# Lakes Michigan–Huron Outflows

# St. Clair and Detroit Rivers 1900–1986

by The Coordinating Committee on
Great Lakes Basic Hydraulic and Hydrologic Data

October 1988

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ST. CLAIR AND DETROIT RIVERS
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COORDINATING COMMITTEE
ON
GREAT LAKES BASIC HYDRAULIC AND HYDROLOGIC DATA

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## SECTION 1

## INTRODUCTION

1.1 Need for Internationally Coordinated Hydraulic and Hydrologic Data. The Great Lakes-St. Lawrence River system (Figure 1) extends southerly and easterly from the headwaters of tributary streams in northern Minnesota and western Ontario to the Gulf of St. Lawrence in the Atlantic Ocean, a distance of about 2,300 miles. The system drains an interior basin of approximately 300,000 square miles to the outlet of Lake Ontario and reaches almost half way across the North American Continent. Eight states of the United States and two provinces of Canada border on the Great Lakes-St. Lawrence River System. The waters of this vast series of lakes and their outlet channels are shared by the United States and Canada. To facilitate the joint use of these waters requires internationally coordinated basic hydraulic and hydrologic data.

1.2 Hydrologic Data. Prior to 1953, responsible Federal agencies in Canada and the United States independently collected and compiled data pertaining to the hydraulic and hydrologic characteristics of the Great Lakes and St. Lawrence River, with only superficial and informal coordination of some of the data. As a consequence, the same basic data developed on different bases and datum planes, were often not compatible. To remedy this situation required a concerted effort to study and evaluate the data used by both countries.

1.3 Establishment of International Study. With the advent of extremely high lake levels in 1952 and the impending hydroelectric power and navigation developments in the St. Lawrence River system, Canadian and U.S. agencies recognized that continued independent development of basic data would be illogical. They realized that early agreement on the hydraulic and hydrologic characteristics of the system was of paramount importance. Therefore, the U.S. Army Corps of Engineers and the Canadian Departments of Transport, Mines and Technical Surveys (now the Department of Energy, Mines and Resources) and Resources and Development (functions of which are now under the Department of Environment Canada and the Department of Energy, Mines and Resources), opened negotiations early in 1953 for the purpose of establishing a basis for development and acceptance of identical data by both countries. The negotiations culminated in a meeting of representatives of the interested agencies in Ottawa on 7 May 1953.

At that meeting, the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data was established. This Committee serves in an advisory capacity to the agencies of the United States and Canada who are charged with the responsibility for collecting and compiling the Great Lakes hydraulic and hydrologic data. The Committee was originally constituted as follows:

CANADA

Chairman
T. M. Patterson,
Water Resources Division,
Department of Resources and Development

Member
J. E. R. Ross,
Geodetic Survey of Canada,
Department of Mines and Technical Surveys

D. M. Ripley,
Special Projects Branch,
Department of Transport

UNITED STATES

Chairman
G. A. Hathaway,
Corps of Engineers,
Department of the Army

Member
E. W. Nelson,
Corps of Engineers,
Department of the Army

W. T. Laidly,
Corps of Engineers,
Department of the Army

The present membership of the Coordinating Committee is as follows:

| CANADA | UNITED STATES |
|---|---|
| Chairman<br>J. R. Robinson,<br>Inland Waters/Lands Directorate,<br>Conservation and Protection Service,<br>Ontario Region, Environment Canada | Chairman<br>D. J. Leonard,<br>Corps of Engineers,<br>North Central Division<br>Department of the Army |
| Member<br>G. M. Yeaton,<br>Canadian Hydrographic Service,<br>Fisheries and Oceans Canada | Member<br>P. C. Morris<br>National Oceanic and Atmospheric Administration,<br>Department of Commerce |
| Secretary<br>P. P. Yee,<br>Inland Waters/Lands Directorate,<br>Conservation and Protection Service,<br>Ontario Region, Environment Canada | Secretary<br>R. E. Wilshaw<br>Corps of Engineers,<br>Detroit District<br>Department of the Army |

Messrs. C. M. Cross, A. T. Prince, R. H. Clark, H. B. Rosenberg, C. A. Gale, R. H. Smith, W. D. Forrester and D. F. Witherspoon have also served as Canadian members or secretaries of the Committee, while Messrs. L. D. Kirshner, F. F. Snyder, H. F. Lawhead, F. A. Blust, C. Thurlow, H. G. Dewey and B. G. DeCooke have served as U.S. members or secretaries of the Committee.

Initially three working groups, designated as the River Flow Subcommittee, the Vertical Control Subcommittee and the Lake Levels Subcommittee, assisted the Coordinating Committee in its work. Later, a Physical Data Subcommittee was established, also to assist this Committee. These subcommittees were directed to conduct the required technical studies through collaboration with the appropriate agencies of Canada and the United States. In September 1969, the membership agreed to combine the Vertical

Control and the Lake Levels Subcommittees into one body known as the Vertical Control-Water Levels Subcommittee. The results being presented in this report were compiled by the River Flow Subcommittee. Current membership on this subcommittee is as follows:

| CANADA | UNITED STATES |
| --- | --- |
| Stephane Dumont,<br>Inland Waters/Lands Directorate<br>Conservation and Protection Service<br>Ontario Region, Environment Canada | R. E. Wilshaw,<br>Corps of Engineers<br>Detroit District<br>Department of the Army |
| L. Kamp,<br>Water Survey of Canada,<br>Inland Waters/Lands Directorate<br>Conservation and Protection Service<br>Ontario Region, Environment Canada | F. H. Quinn,<br>Great Lakes Environmental<br>Research Laboratory<br>National Oceanic and Atmospheric<br>Administration |

Former members of the Subcommittee included Messrs. F. I. Morton and M. Quast for Canada and Messrs. P. Tomandl, P. Cox, I. M. Korkigian and B. G. DeCooke for the United States.

1.4 Purpose and Scope. The River Flow Subcommittee was directed to study the Canadian and U.S. records of Lake Huron outflows through the St. Clair and Detroit Rivers and the methods employed in their derivation. They found that a variety of methods were used in their determination, resulting in a diversity of computed outflows. As a result of this finding, the Subcommittee was further directed to develop a coordinated method of determining the outflows, based upon existing methodology, and then to derive outflows for the entire period of record (1900-1978). The report entitled, "Lakes Michigan-Huron Outflows, St. Clair and Detroit Rivers, 1900-1978" dated December 1982, documented the methods used by the two Governments and presented the outflows derived for the period of record, 1900-1978.

This update report contains flows derived from the 1900-1986 period of record data and documents any additional information available since the publication of the 1982 report.

1.5 Acknowledgements. The Coordinating Committee acknowledges and expresses its appreciation for the cooperation received from the Canadian Conservation and Protection Service, the Detroit District of the U.S. Army Corps of Engineers and the Great Lakes Environmental Research Laboratory of the National Oceanic and Atmospheric Administration. The historical information compiled in this report is primarily from the archives of the U.S. Army Corps of Engineers and the National Oceanic and Atmospheric Administration.

## SECTION 2

## PHYSICAL CONDITIONS AND BASIC DATA

2.1 Description of the St. Clair-Detroit River System. The outflow from Lake Huron is through the St. Clair-Detroit River system. The system is divided into three distinct parts: The St. Clair River (Figure 2), having a length of about 39 miles, including the St. Clair Flats delta; Lake St. Clair (Figure 3), connecting the mouth of the St. Clair River and the head of the Detroit River for a distance of about 26 miles; and the Detroit River (Figure 4), extending about 32 miles to Lake Erie. The fall in water level from Lake Huron to Lake St. Clair is about five feet and from Lake St. Clair to Lake Erie, about three feet.

2.2 Description of the St. Clair River. The St. Clair River has three distinct reaches. The upper reach, extending downstream from Lake Huron to a point about three miles below the International Blue Water Bridge, is about 800 feet wide at its narrowest point and has mid-channel depths varying from about 30 to 70 feet. Maximum velocities for the St. Clair River occur in this reach. The middle reach, which extends downstream for approximately the next 27 miles, is about one-half mile wide and has channel depths varying from 27 to 50 feet. Located in this reach are Stag and Fawn Islands and a middle-ground shoal opposite the City of St. Clair, Michigan. The lower reach extends downstream for the next nine miles to Lake St. Clair, where it divides into a number of channels which flow across a delta called the St. Clair Flats. Average velocities in the St. Clair River, as shown on Figure 5, range from about two to six feet per second, depending upon the reach and controlling characteristics.

During the period 1900-1986, the flow in the St. Clair River averaged about 183,000 cubic feet per second (cfs), with monthly mean discharges ranging between 106,000 cfs and 238,000 cfs.

2.3 Regimen Changes in the St. Clair River. In its natural state, the St. Clair River (Figure 2) had navigation depths of 20 feet or more throughout most of its length, excluding isolated shoals. Near its mouth, the river was divided into several winding channels having natural depths of only four to six feet. In this particular area dredging operations by private interests and by Canadian and U.S. Government agencies have caused regimen changes in the channels.

Improvements in the South Channel of the St. Clair River, including construction of the St. Clair Flats Canal, began in 1855. The opening of the East and West Channels through the Flats, in 1906, probably had some effect on levels. Since this development spanned many years and the water level gauge records were poor, these effects were impossible to quantify. From the beginning of the present century until 1930, a minimum navigation depth of 20 feet was generally available along the entire river.

On August 4, 1900, the Steamer Fontana sank in the narrows at the head of the St. Clair River (Figure 2) and on September 22 of that same year the Steamer Martin sank near the same point. Only the superstructures and machinery of these vessels were removed. Their hulls still lie on the river bottom near the west shore, buried in sand. These wrecks have decreased the cross sectional area of the river at its narrowest point, above the Grand Trunk Railroad gauge, causing a reduction in the capacity of the river; this in turn has affected the level of Lake Huron.

In 1908, commercial interests began to remove sand and gravel from the bed of the river, increasing its discharge capacity. It was estimated that between that date and 1925, three and one-half million cubic yards of sand and gravel were removed, most of it in the reach above the Dry Dock gauge. Sand and gravel dredging was prohibited in U.S. waters above Marysville in 1925 and in Canadian waters shortly thereafter.(9) No determination as to the effect of the dredging was made.

During the period 1920-1922, dredging was performed to improve navigation. This work generally involved the removal of isolated shoals along the river. Below Algonac, commercial interests removed large quantities of sand and gravel from the North Channel.(9)

Two major improvements have been made on the St. Clair River since 1933, namely, dredging for a 25-foot and a 27-foot navigation project. The 25-foot project began in June 1933 and was completed in October 1936. No compensation, or replacement for the dredged material, was provided in connection with the 25-foot project, except to dump spoil material from the dredging operation into the deeper sections of the river. The 27-foot project involved significant excavation in conjunction with the dredging of a new cut-off channel (St. Clair Cutoff in Figure 2), which bypassed the southeast bend in the lower South Channel. Spoil material from this project was used to create a large island between the southeast bend and the cut-off channel. Compensation works were authorized as part of the 27-foot project, but were never constructed. Due to this deepening, the river channel was more efficient and required less slope to flow the same amount of water from Lakes Michigan-Huron to Lake St. Clair. Estimates of the impacts of the 25 and 27 foot projects have been documented.[8]

2.4 <u>St. Clair River Ice.</u> Ice floes from Lake Huron enter the St. Clair River generally under the influence of northerly winds. An analysis of ice retardation for the period 1900-1986 indicates that less ice retardation occurred in the mid 1930's (see Figure 6) following the completion of the 25 foot channel. The figure also shows that construction of the new St. Clair cut-off channel (1960-1962) and further deepening of the channel to 27 feet also decreased the number of occurrences and magnitude of ice retardation. The flow retardation, caused by ice in the St. Clair River during the period 1930 through 1986, averaged about 3,000 cfs in December, 26,000 cfs in January, 28,000 cfs in February, 11,000 cfs in March and about 3,000 cfs in April. This is in comparison with the average for the period 1900 through 1929 of about 4,000 cfs in December, 36,000 cfs in January, 48,000 cfs in February, 23,000 cfs in March and 6,000 cfs in April. This shows that, although significant ice retardation events have occurred (April 1984) where record ice jams have reduced normal river flow by as much as 65%[4], overall ice retardation has been reduced as a result of channel deepening. No attempt has been made to relate these values to the prevailing climatic trends.

2.5 Description of Lake St. Clair. Lake St. Clair (Figure 3) is the shallowest lake within the Great Lakes system. Lake St. Clair has an average depth of 11 feet and a maximum depth of 21 feet, except for the man-made 27 foot navigation channel which bisects the lake. The lake is about 26 miles long and 24 miles wide. Because the lake is relatively small and shallow, it reacts quickly to wind conditions, ice jams and other meteorologic changes.

Navigation channel improvements were made in Lake St. Clair during the periods 1910-1923, 1934-1937 and 1958-1962. The 1934 and 1937 improvements provided a 25 feet deep navigation channel through the lake from the mouth of the South Channel of the St. Clair River to the head of the Detroit River. From 1958 to 1962, this channel was widened and deepened to provide for 27 foot deep navigation.

2.6 Description of the Detroit River. The Detroit River (Figure 4) is about 32 miles long from its head at the Windmill Point Light to its mouth at the Detroit River Light in Lake Erie. The river is characterized by two distinct reaches. The upper reach extends downstream from Lake St. Clair to the head of Fighting Island, about 13 miles. In this reach, the river consists of a single channel averaging about 2,000 feet wide, except directly at its head, where it is divided by Peach (Peche) Island and Belle Isle. The river in this reach is generally deep; the bottom consisting of sand and clay and the channel banks quite steep. Flow velocities, as shown on Figure 7, are fairly uniform, usually less than 2.5 feet per second, even under high flow conditions. However, higher velocities occur in the vicinity of the Ambassador Bridge, where the river slightly narrows to a width of 1,900 feet. Velocities in the center of the channel, in this one and one-half mile reach, are as great as 3.5 to 4.0 feet per second during high flow conditions.

The southerly or lower reach of the Detroit River is broad, with several islands and many shallow expanses. In the upper part of this reach, the banks rise with a gentle slope and the bottom consists of sand, clay, boulders and rock. In the six mile stretch from just downstream of Fighting Island to the south end of Bois Blanc Island, the bottom is mainly bedrock and boulders. The natural formation of the lower river bed has required very extensive rock excavation and dredging to provide navigation channels of suitable width and depth for large vessels engaged in lake commerce. During high flow conditions, velocities in these channels vary from 2.5 to 5.5 feet per second, depending upon the configuration of specific cross-sections.

Three major navigation channels are located in the lower Detroit River. From the head of Fighting Island, the Trenton Channel branches west from the main navigation route (Fighting Island Channel) and separates Grosse Ile from the U.S. mainland. River depths at the south end of the Trenton Channel are less than 10 feet and do not permit through navigation of deep-draft vessels. Thus, a turning basin has been provided which allows deep draft vessels to re-navigate into the Detroit River. Further upstream, at the head of Stony Island, the main navigation route (Ballards Reef Channel) divides into the Livingstone Channel, to accommodate downbound traffic (west of Bois Blanc Island) and the Amherstburg Channel, to accommodate upbound traffic (between Bois Blanc Island and the Canadian mainland).

During the period 1900-1986, the discharge of the Detroit River averaged about 187,000 cfs, with monthly mean discharges ranging between 112,000 cfs and 250,000 cfs.

Water depths in the various reaches of the river vary in accordance with the seasonal levels on Lakes St. Clair and Erie. Fluctuations of several feet (from one to three feet), lasting over periods of several hours, can occur as a result of transient meteorologic phenomena. Fluctuations at the mouth of the Detroit River are produced by high easterly or westerly winds, which cause the water levels to vacillate in Lake Erie. These changes have affected the ends of the lake by as much as eight feet within a five-hour period (December 1-2, 1985), with a water surface slope differential as much as 16 feet between Buffalo, New York and Toledo, Ohio (Figure 8 ).

2.7 Regimen Changes in the Detroit River. In its original state, the Detroit River limited early navigation by the presence of a rock ledge, known as the Limekiln Crossing. This ledge extended east from Stony Island, at a depth of about 13 feet. In 1906, the United States removed 2,632 cubic yards of rock from this ledge, creating a 20 feet deep channel (with a limited width) in this reach of the river. From that time until 1908, improvements to the Crossing continued at scheduled intervals. There is no record of an attempt to balance the effect of this dredging with any form of compensation.

Since 1908, four major changes in the regimen of the river have been defined. The first of these changes was the construction of the Livingstone Channel, between 1908 and 1912. Excavation in the upper part of the channel, in the vicinity of Stony Island, created a channel width of 450 feet. Opening of a 24-foot deep lower channel in 1912, with a width of 300 feet, necessitated leaving cofferdams in place as a form of compensation. Between 1920 and 1922, the Livingstone Channel was widened to 450 feet over its entire length. In addition, the construction of a dike on the west side of the lower part of the channel and the dumping of dredged material, was completed. Figure 4 shows the location of the above improvements. Between 1932 and 1936, the Livingstone Channel was further deepened, to provide for a 25-foot navigation project. A 27-foot navigation project was constructed between 1957 and 1962 by deepening the Fighting Island and Ballards Reef Channels and portions of the Amherstburg Channel. Compensation for these navigation improvements was designed but never constructed.

In 1940, excavation was completed in the Trenton Channel to provide for a turning basin at a point 1,700 feet below the Lower Grosse Ile Bridge and to provide for a 250-foot wide, 21-foot deep channel from the Detroit River to this lower turning basin. In 1964, additional dredging was completed to provide for a 300-foot wide, 27-foot deep channel from the Detroit River to the Upper Grosse Ile Bridge and a channel 300-foot wide and 28-foot deep from about 6000 feet below this bridge to and including an upper Trenton channel turning basin 28 feet deep and 15 acres in area outside the channel limits.

2.8 <u>Detroit River Ice.</u> Ice conditions in the Detroit River are considerably different from those in the St. Clair River. An ice bridge, or arch, usually develops in Lake St. Clair, across the head of the Detroit River, upstream of Peach (Peche) Island. This ice bridge remains stable in the open lake and during periods of subfreezing temperatures the edge extends downstream to Peach (Peche) Island, forming an ice arch on either side of the island. During periods of above freezing temperatures, the ice bridge erodes back into Lake St. Clair and large sheets of ice begin to drift downstream into the upper Detroit River. If Lake Erie ice is fast or jammed in the lower end of the river, ice back-up results. Occasionally, during a prolonged warm spell, or an early spring breakup on Lake St. Clair, the entire river may fill with ice. The remainder of the upper river normally does not freeze over, due to its narrow channel and swift current. One exception is the broad and shallow passage between Belle Isle and the U.S. mainland.

In the lower river, ice cover develops in the broad and shallow areas adjacent to the lower islands; nevertheless, the main navigation channels, particularly the Livingstone Channel, remain open as long as ice entering the channels can pass into Lake Erie. Ice in western Lake Erie is usually fast, but can shift in large sheets under the influence of prevailing winds. Westerly winds can create large areas of open water downstream of the Livingstone Channel, which can absorb most of the ice moving through the system. Easterly winds blow ice into the lower river and cause jams that can raise upstream levels and hamper navigation. Upstream flooding is not a serious problem, because the river banks are steep and most of the shoreline development was designed to tolerate the high levels that could result from occasional wind tide/seiche effects on Lake Erie. This condition has, on rare occasions and for short periods of time, actually reversed the direction of surface flow in the Detroit River. This was authenticated and documented in 1986 by the GLERL from test data recorded at an in-place current meter at the Fort Wayne section.(5) At that time the meter indicated that the direction of flow had turned 180 degrees.

Average ice retardation values in the Detroit River for the period 1900 through 1986 were about 6,000 cfs in December, 14,000 cfs in January, 12,000 cfs in February, 4,000 cfs in March and 1,000 cfs in April.

2.9 <u>Water Level Records--St. Clair-Detroit Rivers.</u> Water level data from the gauge sites shown in Figures 9 and 10, were provided by the Canadian Hydrographic Service and the Water Survey of Canada, the National Ocean Service (NOAA) and the Corps of Engineers.

2.95 <u>Discharge Measurement Records--St. Clair-Detroit Rivers.</u> The location of all discharge measuring sections in the St. Clair and Detroit Rivers from 1900 to 1985, the dates of the measurements at these sections, the number of measurements, the average flow obtained during the metering periods and the levels at pertinent river gauges during the same periods, are being gathered and will be published in another Coordinating Committee report entitled, "Discharge Measurements and Regimen Changes in the Great Lakes Connecting Channels and St. Lawrence River System, 1900-1985." This report is expected to be completed in about 1989 or 1990.

## SECTION 3

## HISTORIC STUDIES TO DETERMINE FLOWS

3.1 Pre-1900 Flow Measurements. Early endeavors to measure the flows in the St. Clair River were generally experimental. In 1867, D.F. Henry conducted the first recorded discharge measurement program in the St. Clair river, using double floats and methods developed as a result of Mississippi River field studies. However, he suspected the measured flows to be nearly 10 percent too high. Henry measured flows in the St. Clair River again in 1868 and 1869, but this time he used his newly developed cup-type current meter (similar to an anemometer) with a unique electrical counter, recording revolutions per second. A comparison of these results with later measurements performed in 1899, at similar stages, showed the 1868-1869 flows to be 5 percent greater. Since little documentation was found concerning these early measurements, they were not considered in this report.

3.2 St. Clair River. In 1933, Sherman Moore compiled a report which presented to date a chronological account of all flow measurements, methods used, gauges, history of dredging and studies on the St. Clair River.[10] Field work between 1924 and 1930, combined with previous extensive measurement programs conducted between 1908 and 1910, extended the range in stage recorded during discharge measurements to over four feet. These efforts led to the development of the first satisfactory discharge equation expressing the relationship between stage and flow. Moore concluded that, because the river carried little or no suspended matter and is confined by stable banks and permanent beds, that no natural changes have occurred in the regime since the time of the earliest water level record.

In 1963, the U.S. Lake Survey prepared a report describing the two major channel improvements, the 25-foot and 27-foot navigation projects, and discussed the methods used to compute the lowering effect of these projects on upstream levels.[8] The report presented an in-depth look at the proposed method of compensation to reduce the effects of dredging.

The proposed method of compensation, using submerged sills, was analyzed on the basis of previous model tests. Korkigian considered that the sills future effectiveness would be reduced by sedimentation.[8] He felt that sediment measurements indicated that the sand transport in the St. Clair River was significant. Korkigian concluded his report by recommending that additional tests be conducted to determine more effective locations for improved sill designs to combat future sedimentation problems. Four alternate methods of compensation were also considered, but nothing was ever constructed. Further analysis of the effects of the proposed sills was presented in a 1972 technical report by the U.S. Army Waterways Experiment Station.[6]

3.3 Detroit River. A 1946 report written by Sherman Moore provides similar documentation on all water level gauges, hydraulic studies and flow measurements conducted on the Detroit River up to 1946.[11]

## SECTION 4

## DETERMINATION OF FLOWS (1900-1978)

Since 1900, dredging and channel improvements in the St. Clair-Detroit River system have changed the slope of the water surface profile between Lakes Huron, St. Clair and Erie. During periods of stable regime, gauge data and flow measurements were analyzed by the U.S. Lake Survey and Water Survey of Canada to determine appropriate stage-flow relationships, which were used to compute flows. The flows computed from these relationships formed the basis for the coordination of the data presented herein.

A publication prepared by the Regulation Subcommittee of the International Great Lakes Levels Board (IGLLB) documented the procedures that were followed in determining flows for the period 1900-1967.(18) In June 1975, the St. Clair River and the Detroit River flows for the years 1900-1958, as coordinated by the Regulation Subcommittee of the IGLLB, were adopted by the Coordinating Committee, and are the flows shown in Tables 2 and 3.

Since 1958, the monthly flows for the St. Clair and Detroit Rivers have been derived independently by both the U.S. and Canada, using both mathematical unsteady flow models and stage-fall discharge equations. The methods used to determine flows for the period 1959-1978 were described in the report entitled, "Lakes Michigan-Huron Outflows St. Clair & Detroit Rivers 1900-1978", dated December 1982. These procedures were used to obtain 1979-1986 flows with the addition of the Great Lakes Environmental Research Laboratory (GLERL) in-place current metering method and unsteady flow models developed by both the Corps of Engineers and GLERL. The methods used for the determination of 1979-1986 flows are described in the following sections.

## SECTION 5

## METHOD USED BY THE GREAT LAKES ENVIRONMENTAL RESEARCH LABORATORY (NOAA) FOR DETERMINATION OF FLOWS (1979-86)

5.1 Unsteady Flow Models. Basic flow computations for 1979-86 were made with numerical flow models developed to simulate unsteady flow rates in the rivers. These models can be operated at hourly or daily time intervals, giving flows tabulated for daily or monthly periods, respectively. The models are based on complete partial differential equations of continuity and motion, expressed in terms of flow Q and stage Z above a fixed datum as follows:

$$\frac{\partial Z}{\partial t} + \frac{1}{T}\frac{\partial Q}{\partial x} = 0 \tag{1}$$

$$\frac{1}{A}\frac{\partial Q}{\partial t} - \frac{2QT}{A^2}\frac{\partial Z}{\partial t} + \left(g - \frac{Q^2T}{A^3}\right)\frac{\partial Z}{\partial x} + \frac{gn^2Q/Q/}{2.208\ A^2R^{4/3}} = 0 \tag{2}$$

where x = the positive flow direction of discharge

t = time

A = channel cross-sectional area

T = top width

g = acceleration due to gravity

R = hydraulic radius

n = Manning's roughness coefficient

$\partial$ = partial derivative function

// = absolute value

Equations (1) and (2) were placed in finite difference form at point M in the implicit computation network (see Figure 11) to yield, respectively,

$$\frac{Zu' + Zd' - Zu - Zd}{2\Delta t} - \frac{\theta\,(Qd' - Qu') + (1-\theta)\,(Qd - Qu)}{T\Delta X} = 0 \qquad (3)$$

$$\frac{Qu' + Qd' - Qu - Qd}{2\,\bar{A}\Delta t} - \frac{\bar{Q}T\,(Zu' + Zd' - Zu - Zd)}{\bar{A}^2\Delta t} +$$

$$(g - \frac{\bar{Q}^2 T}{\bar{A}^3}) \cdot \frac{\theta\,[(Zd' - Zu') + (1-\theta)\,(Zd - Zu)]}{\Delta X} +$$

$$\frac{gn^2\,\bar{Q}/\bar{Q}/}{2.208\;\;\bar{A}^2\;\bar{R}^{4/3}} = 0 \qquad (4)$$

where u and d indicate upstream and downstream locations for a distance increment $\Delta x$, a prime indicates new values at these locations, after time increment $\Delta t$, and overbar indicates mean, such that

$$\theta = \frac{\Delta t'}{\Delta t} \qquad (5)$$

$$\bar{Q} = 0.5\,[\theta\,(Qu' + Qd') + (1-\theta)\,(Qu + Qd)\,] \qquad (6)$$

$$\bar{A} = 0.5\,[\theta\,(Au' + Ad') + (1-\theta)\,(Au + Ad)\,] \qquad (7)$$

Solution of equations (3) and (4) by the implicit method forms the basis of the numerical models. A stable solution for these equations is provided by the weighting coefficient θ, which was selected empirically by Quinn and Wylie[17] to be 0.75. Application of the equations at selected cross-sections for predetermined river reaches produces a set of nonlinear equations that are solved simultaneously with linear approximations by the Newton-Raphson numerical iteration procedure. The predetermined river reaches are bounded by water level gauges, which serve as the model's boundary conditions. These are simply imposed physical limits with known water level conditions, which are needed for the solution of individual model versions that correspond to preselected river reaches. Descriptions of the initial St. Clair and Detroit River models, including calibration, sensitivity analysis, program listings, and output samples, are given by Quinn and Hagman[16]. These initial models have been revised; the modified St. Clair River models are described by Derecki and Kelley[2], and the Detroit River models by Quinn.[14,15]

5.2 Current Meter Flows. Flows in the St. Clair and Detroit Rivers determined by either stage-fall-discharge equations or by unsteady flow numerical models are calibrated from periodic discharge measurements taken over the years during the open-water season. Consequently, these computed flows are reasonably accurate during ice-free periods, but may contain large errors during those winter months having an extensive ice cover. The winter flow discrepancies are usually produced by heavy ice accumulation and ice jamming, primarily taking place in the lower St. Clair River, where an extensive river delta retards the passage of ice flows. To collect winter flow information in the rivers, an in-place current meter measurement program was started in the St. Clair River, with continuous measurements beginning in November 1983. Initial instrumentation consisted of two electromagnetic (EM) current meters (Marsh-McBirney, Inc., Model 585) deployed in the upper river at Port Huron, about 165 and 225 ft from the U.S. shore, in an average water depth of about 45 ft. This instrumentation placement was duplicated on the Detroit River in August 1984, with the meters deployed in the upper river near the Fort Wayne water level gauge, about 200 and 300 ft from the U.S. shore, in an average water depth of about 40 ft. In November 1984, the St. Clair River metering station was augmented with one acoustic Doppler current profiler (ADCP) meter (RD Instruments, Model 1200 RDDR), which provided averaged vertical velocities for approximately 1 m (3.3 ft) consecutive depth segments throughout the water column.

Use of these current meters for continuous measurement of flows in the St. Clair and Detroit Rivers was described by Derecki and Quinn.[5] Periodically, the EM meters gave sharply reduced velocity readings, approaching zero at times, due to frazil ice coating (in winter) or weed accumulation around the sensors (mainly in summer and fall). There were about a half dozen frazil ice episodes occurring on each river per winter, causing short-term (hours or days) data gaps. The weed problem was considered the most serious as it caused long periods (weeks or months) of measured velocity data to be either questionable or erroneous. Frazil ice episodes were easily discernible in the records, presenting no problems in making data corrections. However, weeds have a tendency to build up gradually and the effects are more subtle and difficult to ascertain. With periodic meter inspection and cleaning of sensors by divers, the weed problem was generally manageable in the relatively clean upper St. Clair River, but could not be effectively controlled in the Detroit River which has much heavier weed growth. The St. Clair River ADCP meter was unaffected by frazil ice and weeds, which eliminated most of the data gaps. The quality of data from this meter was also better than the other meters during periods unaffected by frazil ice and weeds, as described by Derecki and Quinn.[5]

Flow estimates from the current meter measurements were obtained by computing daily model-to-meter velocity ratios (eliminating ice affected winter periods) and then multiplying velocities from the meters by the averaged ratios to obtain average river velocities. These velocities were, in turn, multiplied by corresponding cross-sectional areas to produce quantitative river flows.

5.3 <u>Transfer Factors.</u> Monthly hydrologic transfer factors pertaining to Lake St. Clair, for 1979-86, were developed to enable comparison between the St. Clair and Detroit River monthly flows. These transfer factors represent the hydrologic water balance for Lake St. Clair. Ignoring the ground water flux at the lake, which is assumed to be negligible, the transfer factor T is defined by the equation,

$$T = P + R - E - S \tag{8}$$

where $P$ = over-lake precipitation

$R$ = drainage basin runoff

$E$ = lake surface evaporation

$S$ = change in lake storage

The above input parameters were determined independently from available data. The procedure is documented by Quinn.[12] Applying the transfer factor to the Lake St. Clair hydrologic balance yields the flow comparison equation,

$$Q_{SC} + T = Q_D \tag{9}$$

where $Q_{SC}$ = inflow into lake from the St. Clair River

$Q_D$ = outflow from lake into Detroit River.

5.4 St. Clair River Open-Water Flows. Several operational St. Clair River models, based on the one-dimensional equations for continuity and motion described earlier, were developed. These models span the upper portion of the river from Port Huron to the city of St. Clair. Six U.S. water level gauges, located along this river reach, supply data for the models, with three or more gauges included in each model assessment. The extreme gauges (downstream and upstream) form the model's boundary conditions and are used as forcing functions to compute the river profiles and dependent flows. The in-between, or centrally located gauge data (one or more gauges), are included for checking the accuracy of derived flows by comparing computed and measured water levels at the gauges. Each model produces three flow values, corresponding to both the extreme gauges and also the middle water level gauge, to indicate possible flow variations along the employed river reaches due to local inflow. Because of small lateral inflow, differences between these flows are generally insignificant.

The following six model reaches, defined by the above method, are available for the St. Clair River:

1. Ft. Gratiot - Mouth of Black River - Dry Dock (FG-MBR-DD).
2. Dunn Paper - Mouth of Black River - Dry Dock (DP-MBR-DD).
3. Mouth of Black River - Dry Dock - St. Clair (MBR-DD-SC).
4. Ft. Gratiot - Mouth of Black River - St. Clair (FG-MBR-SC).
5. Ft. Gratiot - Dry Dock - St. Clair (FG-DD-SC).
6. Ft. Gratiot - Dunn Paper - Mouth of Black River (FG-DP-MBR).

The open-water period flows were determined by selecting appropriate computed values (normally the average) from three models, usually the first three as shown above. Two models for the Ft. Gratiot - St. Clair reach of the river (nos. 4 and 5) were used only when required. The last model (no. 6), at the head of the river, was used only during those winter months experiencing ice problems. This model represents the portion of the river having the last open-water reach. Because it is so short (2 miles), it does not give dependable open-water flows (large fluctuations). Toward the end of the period (1983-86) being coordinated, flow estimates obtained from the current meter measurements were also used in the selection process for determining river flows. Model results were compared with the current meter derived flows and adjustments were made where appropriate (after consideration of those weed effects or other meter problems indicated on the data records).

5.5 <u>St. Clair River Winter Flows.</u> Three models (nos. 1 to 3) plus the last model (no. 6) were generally used to compute winter flows. However, during winter, there is generally less agreement among St. Clair River models, and frequent discrepancies occur between the St. Clair River and Detroit River flows. This discrepancy between the models is due to ice retardation, which occurs quite often, especially in the lower St. Clair River. Complete resolution of the ice retardation problem would require winter flow measurements; this was demonstrated by Derecki and Quinn[3,4] for the record St. Clair River ice jam of April 1984.

Winter flows for the St. Clair River were determined by approximately the same procedure used during open-water periods. However, computed flows were examined for possible ice effects, and the flows indicating the least discharge were normally used. During the last three winters, considerable emphasis was given to flows estimated from the current meter measurements, in comparison with model-simulated flows. Some consideration was also given to flows determined by transferring Detroit River flows, but the St. Clair River models produce flows that are normally assumed to be more representative of actual conditions.

5.6 Detroit River Open-Water Flows. Two different unsteady flow models were developed for the Detroit River. One is the upper river model, which spans the river from Windmill Point to Wyandotte. The other is the total river model (Windmill Point to Fermi), which branches into two channels in the lower reach to give separate flows around Grosse Ile. Operation of both models is similar, except the total Detroit River model provided four additional flow values, corresponding to the upstream and downstream sections of the branching channels. Both model-simulated flows and transferred St. Clair River flows were used to make a final selection of the Detroit River flows. Flow estimates determined from the last three years of the current meter program were generally so affected by weeds and instrument problems, that they could not be used during most months. The three-gauge designations for the two models are as follows:

1. Windmill Pt. - Ft. Wayne - Wyandotte (WP-FW-WY).
2. Windmill Pt. - Wyandotte - Fermi (WP-WY-FE).

5.7 Detroit River Winter Flows. Both of the above models were used to compute winter flows, but the upper river model is considered more reliable, since it spans what is normally an ice-free reach. However, when discrepancies occurred between computed flows for the Detroit and St. Clair Rivers, the recommended Detroit River flows were based primarily on the transferred St. Clair River flows. Only partial current meter flow estimates were available for the last two winter seasons and did not provide much help in the flow selection process.

## SECTION 6

## METHOD USED BY THE U.S. ARMY CORPS OF ENGINEERS FOR DETERMINATION OF FLOWS (1979-86)

6.1 Unsteady Flow Models. Hydraulic transient models, similar to those used by the Great Lakes Environmental Research Laboratory, were developed to simulate unsteady flow rates in the connecting channels of the Great Lakes. These hydraulic transient models rely on the simultaneous solution of the mass continuity and momentum equations to determine discharge, stage and velocity at specific points along a channel. These equations, expressed in terms of flow "Q", velocity "V" and stage "Z" above a fixed datum are shown below:

$$\frac{\partial Q}{\partial x} + B\frac{\partial Z}{\partial t} = 0 \qquad (10)$$

$$\frac{\partial Q}{\partial t} + \frac{V\partial Q}{\partial x} + \frac{Q\partial V}{\partial x} + gA\frac{\partial Z}{\partial x} + \frac{gn^2\, Q/Q/}{2.208\, A\, R^{4/3}} = 0 \qquad (11)$$

where x = the positive flow direction of discharge

t = time

A = channel cross-sectional area

B = top width

g = acceleration due to gravity

R = hydraulic radius

n = Manning's roughness coefficient

$\partial$ = partial derivative function

// = absolute value

V = mean value of velocity

The derived equations consist of independent variables x and t and dependent variables n and Q or V. The other terms are constants or are functions of the dependent and independent variables. Equation (11) can be rewritten in terms of velocity or flow to simplify calculations. Equations (10) and (11) above, placed in finite difference form at point M in the implicit computation network (Figure 11) yield equations similar to those presented in Section 5.1.

The solution of the finite difference forms of the equations by the implicit method is accomplished through simultaneous solution with linear approximations by the Newton-Raphson numerical iterative procedure. As with the GLERL models, the weighting coefficient $\theta$ was selected to be 0.75. Models have been developed for the St. Clair and Detroit Rivers. These models have been used since 1979 for flow computation and hydraulic simulation studies.[19]

6.2 Stage-Discharge Relationships. Two-gauge stage-fall-discharge relationships were developed for various gauge combinations in both the St. Clair and Detroit Rivers. The equations were calibrated using recorded water level data and field measured discharge data. Particular emphasis was placed upon inclusion of relationships in the ice-free reaches of both rivers to obtain reasonable estimates of winter flows. The basic equation is of the form:

$$Q = K\,[(P\,(Hu) + (1 - P)(Hd) - Ym)]^{a}\,(Hu - Hd)^{b} \tag{12}$$

where P = a weighting factor, i.e., .1, .2, .3 to .9

Hu = water level at the upstream gauge

Hd = water level at the downstream gauge

Ym = hydraulic elevation at the river bottom.

K,a,b = derived constants

Studies and analyses, by the Governments of the United States and Canada, have yielded the mutually agreed upon values of a=2.0 and b=0.5 for the St. Clair River and for the Detroit River. Solutions for the constant "K" and hydraulic elevation at the river bottom "Ym" were obtained through analyses of the average water levels and measured flows.

To obtain a precise gage relationship, "P" is varied with each iteration to produce a linear equation based upon the least square fit Y vs. X (nine equations for each gauge relationship). The one equation in each group exhibiting the least standard error was selected to represent a particular water level gauge combination.

In 1983 new relationships were derived for the subject waterways. The new equations were derived from water levels and measured flows collected from 1959-1982. Beginning in 1983, daily and monthly flows were computed using these new relationships.

6.3 St. Clair River Open-Water Flows. Open-water flows were determined through model simulation and by application of gauge relationships.

An operational St. Clair River model, based on the one-dimensional equations for continuity and motion, was developed for the entire river in 1979. Nine U.S. water level gauges supplied data for the model for the simulation of daily flows. Upstream and downstream stage hydrographs were used as forcing functions, maintaining the river profile, for computation of daily flow. The observed water level readings were compared to calculated values for verification and calibration. The averages of computed flows were calculated to determine monthly mean values for each reach.

The St. Clair River model extends from above Port Huron, at the outlet of Lake Huron, to Algonac, where the St. Clair Flats begin. The model consists of eight reaches. The eight reaches of the model correspond to the water level gauges listed below.

1. Fort Gratiot (FG)
2. Dunn Paper (DP)
3. Mouth of Black River (MBR)
4. Dry Dock (DD)
5. Marysville (MAR)
6. St. Clair (SC)
7. Marine City (MC)
8. Roberts Landing (RL)
9. Algonac (ALG)

In conjunction with the St. Clair River model, open-water flows were determined by stage-flow relationships. These relationships covered reaches of the river where adequate water level data were readily available. The stage-discharge equation for each relationship provided a daily flow, based on recorded water levels for the river reach involved. Computed flows for each stage-discharge equation were averaged to obtain a daily mean St. Clair River flow and the daily values were in turn averaged to obtain a monthly St. Clair River flow. In addition, flows from selected gauge relationships were averaged to provide values for specific locations on the river (upper river, lower river, etc.). The following reaches (relationships) were selected for computing St. Clair River flows:

Fort Gratiot - Mouth of Black River (FG-MBR)
Fort Gratiot - Dry Dock (FG-DD)
Fort Gratiot - Marysville (FG-MAR)
Fort Gratiot - St. Clair (FG-SC)
Fort Gratiot - Algonac (FG-ALG)
Fort Gratiot - St. Clair Shores (FG-SCS)
Dunn Paper - Mouth of Black River (DP-MBR)
Dunn Paper - Dry Dock (DP-DD)
Dunn Paper - Marysville (DP-MAR)
Dunn Paper - St. Clair (DP-SC)
Dunn Paper - Algonac (DP-ALG)
Dunn Paper - St. Clair Shores (DP-SCS)
Mouth of Black River - Dry Dock (MBR-DD)
Mouth of Black River - Marysville (MBR-MAR)
Mouth of Black River - St. Clair (MBR-SC)
Mouth of Black River - Algonac (MBR-ALG)
Mouth of Black River - St. Clair Shores (MBR-SCS)
Dry Dock - Marysville (DD-MAR)
Dry Dock - St. Clair (DD-SC)
Dry Dock - Algonac (DD-ALG)
Dry Dock - St. Clair Shores (DD-SCS)
St. Clair - St. Clair Shores (SC-SCS)

Computed flows, determined by the methods presented above, were analyzed, month by month, through the period 1979-1986 to determine one mean value per month for each river, rejecting large or disproportionate values and averaging the remaining values. Some final flows received minor adjustments when application of transfer factors to the computed flows of both rivers, as defined earlier, produced values that were considered unreasonable.

6.4 <u>St. Clair River Winter Flows.</u> The unsteady flow model and the stage discharge relationships were used for computation of winter flows. Simulation of winter flows using the model provided satisfactory results when compared with other methods. Flows determined by the stage discharge relationships used primarily those reaches considered to be ice-free.

Model simulation required the determination of roughness coefficients for the ice covered channels. Once a determination of the roughness had been made, flows were simulated for varying time increments. Additional model calibration to actual winter flow measurements allowed for significant improvement in the precise computation of the flows occurring under an ice cover. The resulting flows from computer simulation compared favorably with those obtained by GLERL and by use of the stage discharge equations.

The expanded form of the stage-fall equations used for open-water periods does not adequately represent the flows during periods of ice retardation. From December through March, computed winter flows are higher whenever retardation affects the normal stage-fall relationships. However, as determined from years of visual observations and photographs, the reaches FG-MBR, FG-DD and MBR-DD appear to be ice-free much of the winter. In addition, the greatest fall in water surface elevation occurs in these short reaches, minimizing the error in determining the slope. Therefore, relationships FG-MBR, FG-DD and MBR-DD were given greater weight when determining monthly winter flows, especially when the flows computed from the remaining stage-discharge equations were much higher.

To aid in the determination of the occurrence of ice retardation, flows computed by the gauge relationships were plotted vs. time. From these plots a clear indication of the beginning of ice retardation could be identified by the divergence of plotted values. Once ice retardation was determined, daily winter flows were determined using the methods discussed above.

6.5 Detroit River Open-Water Flows. Open-water flows for the Detroit River were determined by using two-gauge stage-fall-discharge relationships. Similar procedures, as outlined above for the St. Clair River , were followed when determining these flows. Adequate water level data were available at each of the gauge sites represented in the reaches shown below. Monthly flows were determined using the same procedure used for the St. Clair River, computing daily flows and averaging monthly flows. Flows computed in this manner were compared to flows derived using those computed for the St. Clair River, plus Lake St. Clair transfer factors. The best of either method was used to represent the monthly Detroit River flows. Adjustments were also required whenever the water level data were considered inconsistent or incomplete. As in the St. Clair River, new flow relationships were derived, and beginning in 1983, flows were computed using these relationships. The following reaches (relationships) were used:

St. Clair Shores - Wyandotte (SCS-WYN)
Windmill Point - Fort Wayne (WP-FW)
Windmill Point - Wyandotte (WP-WYN)
Windmill Point - Gibraltar (WP-GIB)
Fort Wayne - Wayandotte (FW-WYN)
Fort Wayne - Gibraltar (FW-GIB)
Wyandotte - Gibraltar (WYN-GIB)

6.6 Detroit River Winter Flows. As for the St. Clair River, the open water relationships do not adequately represent flows during periods of ice retardation. During the winter, the predominantly ice-free reach in the Detroit River is WP-FW. This reach also happens to exhibit the greatest fall in water surface elevation. Therefore, the computed daily WP-FW flow served as a guide to determine the daily mean winter flow. Whenever the computed WP-FW flow fell below the mean flow determined from the other equations, that value received preference as the selected daily flow.

Whenever the computed WP-FW flow was equal to or greater than the mean, all equations received equal consideration. As in the selection of open-water flows, consideration was also given to flows computed using the St. Clair River flows and the transfer factors (described in Section 6.4).

# SECTION 7

## UNITED STATES COORDINATION OF FINAL FLOWS (1979-1986)

7.1 St. Clair River Open-Water Flows. Review of the monthly flows for the years 1979-1986, as determined by the Great Lakes Environmental Research Laboratory and the U.S. Army Corps of Engineers, indicated differences averaging only about 2,000 cubic feet per second. As a result, the U.S. members of the River Flow Subcommittee agreed to an initial selection from the mean of the listed values. These flows were later reviewed for compatibility with the flows computed for the Detroit River, which were similarly coordinated by the Corps of Engineers and the Great Lakes Environmental Research Laboratory.

7.2 St. Clair River Winter Flows. The principles used by the representatives in selecting winter flows paralleled those for the open-water period. The winter flows were initially selected as the mean of the two independently determined flows, with final selection based on a review of gauge records and compatability with Detroit River flows.

7.3 Detroit River Open-Water and Winter Flows. The principles used are generally the same as those outlined for the St. Clair River. However, with regard to initial flow and final flow determinations, consideration was also given to the effect of the local drainage of the entire system on the derived Detroit River flow, as well as the transfer factors.

## SECTION 8

## METHOD USED BY CANADA
## FOR DETERMINATION OF FLOWS (1979-86)

8.1 Transfer Factors. In order to achieve compatibility between the St. Clair and Detroit River flows, a simple water balance equation (similar to the equation in Section 5.3 was used to estimate net basin supplies to Lake St. Clair for the period 1979 to 1986.

Flows of the Clinton, Rouge, Thames and Sydenham Rivers were used to compute local inflow. The ungauged area was assumed to have the same average runoff as the gauged area represented by the above rivers. Evaporation was computed using a mass transfer method. Water temperatures were obtained from the mean values measured in the St. Clair River and Lake St. Clair. Other meteorological data were obtained from shore stations. Precipitation on the lake was computed from stations on or near the shores of Lake St. Clair. These values, with adjustments for storage change in Lake St. Clair, were used as transfer factors in the selection of St. Clair and Detroit River flows. The transfer factors developed by the Canadian section of the River Flow Subcommittee are given in Table 1.

8.2 St. Clair River Open-Water Flows. Subsequent to 1958, discharge measurements were made in 1959, 1960, 1962, 1963, 1964, 1966 and 1968 at the Bay Point Section, in 1968 at the Roberts Landing Section and in 1973 at the Dry Dock and Roberts Landing Sections. Using all of the available measurements, the Canadian Section of the River Flow Subcommittee developed a basic discharge equation for the Dunn Paper-Port Lambton Reach of the St. Clair River. The form of the equation used was as follows:

$$Q = K[a(Hu - Hw) + b(Hd - Hw)]^2 [Hu - Hd]^{0.5} \qquad (13)$$

where Hu = the level at the upstream gauge

Hd = the water level at the downstream gauge

Hw = the hydraulic elevation of the river bottom.

The least squares curve fitting method was used to derive an equation, using an upstream and downstream water level and a measured discharge.

Using the computed mean monthly flows for the Dunn Paper-Port Lambton reach of the river, a relationship for the Harbor Beach-St. Clair Shores reach was derived for the open-water months (May through November). The flows computed from this relationship (Harbor Beach-St. Clair Shores) were generally adopted by the Canadian Section of the River Flow Subcommittee as the open-water flows for the St. Clair River, and then used to derive relationships for all other reaches of the river for which water level data were available. Relationships were derived using the following water level gauges:

Harbor Beach
Fort Gratiot
Dunn Paper
Point Edward
Mouth of Black River
Dry Dock
Marysville
St. Clair
Port Lambton
Algonac
St. Clair Shores

In most instances, the mean monthly flow selected was that for the Harbor Beach-St. Clair Shores reach of the river. However, consideration was also given to flows derived for other reaches, as well as the Detroit River flows and the transfer factors.

8.3 <u>St. Clair River Winter Flows.</u> To select a flow for each winter month, the flows were computed from the derived relationships, for all months and for all reaches. The flow selected was generally that obtained by using the criteria of the minimum flow for the longest reach for which water levels were available. This is based on the reasoning that as the ice cover moves upstream of the lower gauge, the reach has a steep slope from which a high discharge would be computed. Above the ice cover, the river has a flatter slope, due to backwater from the ice and therefore, would have a lower discharge. The longest reach was used whenever possible, since it is assumed that the longer the reach the greater the fall in water surface and, therefore, the less relative error in the measurement of the slope. As in the selection of the open-water flows, consideration was also given to the derived Detroit River flows, as well as the transfer factors.

8.4 Detroit River Open-Water Flows. For the period 1979 to 1986, the discharge equations developed for the Detroit River were identical in form to those used for the St. Clair River (see Section 8.2). The field measurements made at the Fort Wayne section, during the period 1959-1973, were used to derive discharge equations by a least squares analysis.

Using the computed mean monthly flows for the Windmill Point-Fort Wayne reach of the river, a relationship for St. Clair Shores to Cleveland was developed for the open-water months (May to November). The flows computed from this relationship were then used to derive relationships for all other reaches of the river for which water level data were available. The following water level gauges were used in the development of discharge equations for the Detroit River:

St. Clair Shores
Windmill Point
Fort Wayne
Wyandotte
Gibraltar
Toledo
Cleveland

The developed relationships are on file with the working papers of the Canadian Section of the River Flow Subcommittee.

The final flow selection was made from a consideration of the flow derived from the various discharge relationships (usually St. Clair Shores to Cleveland) as well as the St. Clair flows and the transfer factors.

8.5 Detroit River Winter Flows. The principles used for determination of Detroit River winter flows were similar to those used on the St. Clair River. Generally, the flow was selected as the minimum flow for the longest reach for which water levels were available. However, consideration was given to the St. Clair River flow and transfer factors.

## SECTION 9

## INTERNATIONAL COORDINATION OF FINAL FLOWS (1979-1986)

9.1 St. Clair-Detroit Rivers Open Water Flows. A review was conducted, by both U.S. and Canadian members of the River Flow Subcommittee, of the monthly flows determined independently by each section of the Subcommittee. Generally, most flows were in close accord and a single value was selected based on agreement by participating members. Those flows that varied more than five percent were identified for further study and subjected to a second review. All flows were later reviewed for compatibility with gauge records, transfer factors and interrelation of one river with another, until both sections of the River Flow Subcommittee agreed to a final coordinated value.

9.2 St. Clair-Detroit Rivers Winter Flows. The principles used by members of the River Flow Subcommittee for selection of winter flows were similar to those for the open-water period. The winter flows were initially selected as the mean of the independently determined flows, with final selection based on a review of water level gauge records, transfer factors and compatibility with flows computed for both rivers.

The coordinated monthly flows for the St. Clair and Detroit Rivers, 1900 through 1986, are shown in Tables 2 and 3. All working data employed in the determination of the flows are on file in the offices of the U.S. Army Corps of Engineers, Detroit District, Detroit , Michigan and the Inland Waters/Lands Directorate, Environment Canada, Cornwall, Ontario.

TABLE 1

Factors for Transferring St. Clair River Flows
To Detroit River Flows
(1000 cfs)

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1959 | 4 | 3 | 11 | 12 | 4 | 1 | 2 | 2 | 1 | 5 | 6 | 8 |
| 1960 | 13 | 3 | 2 | 19 | 4 | 7 | 0 | 1 | 1 | 2 | 2 | -1 |
| 1961 | 3 | 2 | 6 | 6 | 4 | 2 | 2 | 4 | 3 | 2 | 3 | 1 |
| 1962 | 9 | 0 | 9 | 5 | 1 | 2 | 1 | 2 | 1 | 2 | 4 | 0 |
| 1963 | 5 | 0 | 7 | 5 | 3 | 2 | 1 | 0 | 0 | 0 | 0 | -1 |
| 1964 | 7 | 2 | 1 | 5 | 2 | 2 | 1 | 3 | 1 | 0 | 1 | 2 |
| 1965 | 9 | 10 | 7 | 12 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 6 |
| 1966 | 4 | 6 | 6 | 5 | 2 | 2 | 2 | 2 | 2 | 1 | 4 | 9 |
| 1967 | 4 | 5 | 8 | 13 | 1 | 5 | 4 | 2 | 1 | 6 | 9 | 16 |
| 1968 | 7 | 17 | 11 | 7 | 4 | 9 | 6 | 3 | 1 | 2 | 2 | 7 |
| 1969 | 7 | 9 | 6 | 11 | 7 | 4 | 4 | 2 | 0 | 1 | 4 | 8 |
| 1970 | -1 | 3 | 5 | 11 | 2 | 2 | 2 | 0 | 0 | 2 | 3 | 4 |
| 1971 | 6 | 5 | 11 | 5 | -2 | 0 | 0 | 0 | 2 | 2 | 1 | 4 |
| 1972 | 2 | 3 | 9 | 11 | 2 | 0 | 2 | 3 | 2 | 3 | 8 | 9 |
| 1973 | 13 | 5 | 20 | 8 | 4 | 5 | 4 | 2 | 0 | 3 | 5 | 6 |
| 1974 | 12 | 10 | 15 | 10 | 9 | 2 | 2 | 2 | 2 | 0 | 2 | 4 |
| 1975 | 8 | 9 | 12 | 12 | 3 | 3 | 2 | 3 | 8 | 3 | 5 | 4 |
| 1976 | 7 | 14 | 20 | 7 | 8 | 2 | 6 | 4 | 2 | 3 | 5 | 3 |
| 1977 | -2 | 4 | 20 | 12 | 2 | 2 | 2 | 0 | 2 | 6 | 5 | 7 |
| 1978 | 4 | 2 | 13 | 16 | 4 | 2 | 2 | 1 | 1 | 2 | 3 | 2 |
| 1979 | 4 | -1 | 15 | 18 | 4 | 2 | 3 | 1 | 0 | 2 | 6 | 7 |
| 1980 | 6 | 3 | 9 | 13 | 4 | 4 | 3 | 5 | 4 | 3 | 2 | 7 |
| 1981 | -2 | 14 | 8 | 5 | 4 | 1 | 2 | 3 | 4 | 13 | 6 | 5 |
| 1982 | 4 | 2 | 20 | 14 | 2 | 4 | 4 | 2 | 2 | 2 | 8 | 12 |
| 1983 | 6 | 6 | 4 | 9 | 11 | 4 | 4 | 5 | 2 | 3 | 7 | 5 |
| 1984 | 5 | 16 | 10 | 12 | -3 | 4 | 2 | 2 | 3 | 3 | 6 | 5 |
| 1985 | 7 | 12 | 22 | 13 | 2 | 2 | 3 | 5 | 5 | 4 | 12 | 4 |
| 1986 | 9 | 6 | 16 | 6 | 2 | 4 | 3 | 2 | 5 | 11 | 4 | 10 |

TABLE 2
St. Clair River
Coordinated Monthly Mean Outflows
(1000 cfs)

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1900 | 148 | 140 | 140 | 181 | 185 | 187 | 192 | 193 | 196 | 197 | 199 | 192 |
| 1901 | 166 | 126 | 154 | 127 | 194 | 202 | 204 | 204 | 200 | 198 | 196 | 187 |
| 1902 | 146 | 152 | 183 | 186 | 188 | 192 | 191 | 194 | 190 | 186 | 187 | 182 |
| 1903 | 141 | 137 | 173 | 185 | 185 | 188 | 192 | 192 | 194 | 198 | 192 | 182 |
| 1904 | 153 | 148 | 154 | 187 | 192 | 202 | 204 | 205 | 204 | 205 | 201 | 189 |
| 1905 | 126 | 139 | 161 | 196 | 200 | 204 | 206 | 207 | 207 | 206 | 202 | 198 |
| 1906 | 193 | 150 | 170 | 200 | 204 | 204 | 206 | 205 | 202 | 198 | 196 | 182 |
| 1907 | 156 | 145 | 173 | 197 | 199 | 202 | 206 | 205 | 206 | 202 | 198 | 194 |
| 1908 | 140 | 132 | 167 | 192 | 198 | 204 | 208 | 206 | 201 | 196 | 192 | 190 |
| 1909 | 170 | 122 | 154 | 184 | 190 | 195 | 197 | 195 | 194 | 190 | 184 | 178 |
| 1910 | 138 | 140 | 178 | 182 | 186 | 189 | 187 | 186 | 185 | 185 | 182 | 169 |
| 1911 | 135 | 130 | 170 | 173 | 180 | 183 | 184 | 184 | 180 | 180 | 178 | 175 |
| 1912 | 136 | 141 | 156 | 168 | 177 | 188 | 188 | 191 | 192 | 194 | 194 | 194 |
| 1913 | 184 | 146 | 165 | 184 | 192 | 199 | 202 | 200 | 196 | 198 | 196 | 191 |
| 1914 | 154 | 154 | 161 | 184 | 186 | 190 | 191 | 191 | 192 | 190 | 190 | 176 |
| 1915 | 131 | 149 | 171 | 181 | 180 | 182 | 182 | 182 | 182 | 182 | 182 | 177 |
| 1916 | 164 | 142 | 145 | 180 | 188 | 194 | 200 | 200 | 199 | 196 | 198 | 194 |
| 1917 | 160 | 160 | 192 | 194 | 198 | 202 | 209 | 211 | 206 | 203 | 202 | 168 |
| 1918 | 144 | 161 | 176 | 161 | 214 | 218 | 215 | 212 | 209 | 203 | 204 | 200 |
| 1919 | 190 | 185 | 187 | 190 | 198 | 197 | 200 | 198 | 195 | 192 | 191 | 191 |
| 1920 | 123 | 132 | 167 | 193 | 197 | 199 | 202 | 200 | 201 | 198 | 192 | 188 |
| 1921 | 185 | 136 | 179 | 181 | 190 | 190 | 189 | 188 | 184 | 185 | 178 | 180 |
| 1922 | 144 | 134 | 164 | 181 | 188 | 193 | 193 | 192 | 189 | 186 | 183 | 177 |
| 1923 | 134 | 136 | 150 | 171 | 175 | 184 | 183 | 183 | 182 | 180 | 176 | 169 |
| 1924 | 150 | 122 | 154 | 162 | 169 | 177 | 178 | 180 | 180 | 175 | 169 | 150 |
| 1925 | 133 | 130 | 148 | 162 | 166 | 165 | 166 | 164 | 160 | 160 | 156 | 157 |
| 1926 | 110 | 115 | 127 | 153 | 161 | 166 | 166 | 165 | 162 | 160 | 158 | 159 |
| 1927 | 113 | 123 | 146 | 166 | 172 | 178 | 178 | 178 | 174 | 176 | 172 | 170 |
| 1928 | 142 | 116 | 137 | 180 | 187 | 188 | 190 | 194 | 196 | 198 | 201 | 198 |
| 1929 | 169 | 164 | 191 | 202 | 214 | 218 | 220 | 220 | 216 | 208 | 208 | 178 |
| 1930 | 160 | 166 | 192 | 190 | 194 | 198 | 202 | 202 | 198 | 192 | 186 | 180 |
| 1931 | 147 | 111 | 124 | 175 | 176 | 174 | 175 | 170 | 166 | 166 | 168 | 164 |
| 1932 | 157 | 158 | 134 | 162 | 160 | 163 | 166 | 165 | 161 | 159 | 156 | 145 |
| 1933 | 149 | 116 | 145 | 151 | 155 | 162 | 162 | 162 | 158 | 156 | 155 | 146 |
| 1934 | 108 | 121 | 132 | 154 | 156 | 158 | 159 | 160 | 159 | 159 | 155 | 157 |
| 1935 | 129 | 149 | 150 | 160 | 161 | 164 | 167 | 167 | 164 | 163 | 162 | 141 |
| 1936 | 135 | 133 | 150 | 166 | 170 | 173 | 172 | 169 | 171 | 172 | 168 | 161 |
| 1937 | 159 | 122 | 161 | 157 | 163 | 165 | 164 | 164 | 166 | 165 | 165 | 154 |
| 1938 | 127 | 145 | 132 | 168 | 174 | 178 | 182 | 184 | 183 | 182 | 180 | 176 |
| 1939 | 158 | 140 | 144 | 171 | 180 | 184 | 188 | 190 | 190 | 188 | 185 | 180 |

TABLE 2
(Continued)
St. Clair River
Coordinated Monthly Mean Outflows
(1000 cfs)

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1940 | 126 | 143 | 152 | 168 | 171 | 174 | 176 | 176 | 179 | 176 | 174 | 171 |
| 1941 | 140 | 130 | 155 | 168 | 177 | 176 | 176 | 173 | 174 | 178 | 181 | 180 |
| 1942 | 147 | 106 | 162 | 181 | 185 | 189 | 190 | 189 | 188 | 186 | 184 | 177 |
| 1943 | 140 | 148 | 164 | 186 | 184 | 196 | 202 | 208 | 208 | 205 | 204 | 198 |
| 1944 | 149 | 164 | 168 | 192 | 194 | 196 | 198 | 198 | 198 | 198 | 194 | 190 |
| 1945 | 150 | 162 | 181 | 183 | 186 | 194 | 199 | 198 | 196 | 194 | 195 | 187 |
| 1946 | 165 | 160 | 195 | 201 | 200 | 198 | 199 | 196 | 194 | 190 | 188 | 185 |
| 1947 | 151 | 148 | 177 | 174 | 184 | 190 | 198 | 198 | 198 | 198 | 198 | 192 |
| 1948 | 173 | 166 | 176 | 190 | 194 | 194 | 195 | 195 | 190 | 184 | 180 | 178 |
| 1949 | 171 | 162 | 153 | 174 | 178 | 178 | 182 | 181 | 178 | 172 | 170 | 163 |
| 1950 | 153 | 134 | 142 | 161 | 170 | 176 | 182 | 187 | 186 | 186 | 186 | 178 |
| 1951 | 155 | 156 | 180 | 187 | 198 | 201 | 208 | 211 | 210 | 214 | 214 | 210 |
| 1952 | 203 | 202 | 203 | 215 | 220 | 224 | 224 | 228 | 226 | 222 | 215 | 213 |
| 1953 | 209 | 201 | 204 | 206 | 214 | 216 | 220 | 221 | 218 | 214 | 210 | 204 |
| 1954 | 169 | 157 | 197 | 196 | 204 | 208 | 214 | 214 | 211 | 213 | 214 | 210 |
| 1955 | 195 | 185 | 197 | 201 | 206 | 206 | 206 | 202 | 194 | 190 | 188 | 183 |
| 1956 | 144 | 142 | 166 | 181 | 180 | 189 | 190 | 190 | 188 | 185 | 184 | 180 |
| 1957 | 146 | 156 | 173 | 172 | 174 | 178 | 182 | 180 | 180 | 176 | 176 | 173 |
| 1958 | 141 | 132 | 164 | 164 | 176 | 172 | 172 | 171 | 169 | 166 | 165 | 154 |
| 1959 | 118 | 128 | 151 | 155 | 166 | 171 | 172 | 173 | 174 | 173 | 175 | 173 |
| 1960 | 164 | 148 | 165 | 173 | 190 | 196 | 204 | 205 | 204 | 202 | 198 | 187 |
| 1961 | 174 | 180 | 183 | 182 | 182 | 184 | 187 | 187 | 187 | 189 | 188 | 182 |
| 1962 | 153 | 147 | 173 | 181 | 187 | 188 | 188 | 185 | 186 | 180 | 174 | 164 |
| 1963 | 142 | 132 | 152 | 162 | 168 | 171 | 172 | 173 | 170 | 168 | 166 | 156 |
| 1964 | 133 | 127 | 146 | 147 | 155 | 156 | 159 | 160 | 161 | 161 | 159 | 154 |
| 1965 | 131 | 133 | 144 | 155 | 166 | 170 | 172 | 174 | 175 | 180 | 178 | 174 |
| 1966 | 171 | 162 | 170 | 177 | 182 | 182 | 184 | 181 | 180 | 177 | 172 | 171 |
| 1967 | 167 | 156 | 167 | 176 | 183 | 186 | 192 | 192 | 190 | 184 | 188 | 180 |
| 1968 | 163 | 164 | 176 | 178 | 183 | 186 | 192 | 196 | 197 | 198 | 197 | 189 |
| 1969 | 164 | 181 | 186 | 190 | 196 | 202 | 208 | 212 | 210 | 207 | 206 | 195 |
| 1970 | 150 | 166 | 191 | 192 | 199 | 204 | 206 | 207 | 207 | 204 | 204 | 200 |
| 1971 | 184 | 176 | 196 | 205 | 211 | 214 | 218 | 218 | 215 | 212 | 210 | 203 |
| 1972 | 198 | 188 | 192 | 194 | 208 | 214 | 214 | 218 | 222 | 221 | 216 | 210 |
| 1973 | 207 | 194 | 201 | 214 | 221 | 225 | 228 | 230 | 228 | 225 | 222 | 214 |
| 1974 | 200 | 202 | 206 | 210 | 219 | 227 | 232 | 229 | 226 | 220 | 218 | 210 |
| 1975 | 201 | 196 | 192 | 206 | 216 | 220 | 223 | 220 | 218 | 212 | 207 | 205 |
| 1976 | 167 | 176 | 194 | 212 | 220 | 222 | 223 | 220 | 214 | 208 | 201 | 182 |
| 1977 | 148 | 165 | 182 | 188 | 189 | 191 | 191 | 192 | 188 | 188 | 192 | 182 |
| 1978 | 170 | 166 | 173 | 179 | 186 | 192 | 198 | 199 | 200 | 204 | 200 | 192 |
| 1979 | 159 | 167 | 188 | 196 | 210 | 212 | 216 | 219 | 216 | 211 | 208 | 205 |

TABLE 2
(Continued)
St. Clair River
Coordinated Monthly Mean Outflows
(1000 cfs)

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1980 | 201 | 197 | 194 | 198 | 204 | 208 | 210 | 209 | 209 | 209 | 206 | 200 |
| 1981 | 165 | 184 | 197 | 198 | 204 | 204 | 206 | 205 | 207 | 200 | 200 | 196 |
| 1982 | 163 | 162 | 175 | 183 | 194 | 195 | 197 | 202 | 202 | 199 | 198 | 194 |
| 1983 | 193 | 193 | 199 | 198 | 204 | 214 | 216 | 212 | 212 | 210 | 205 | 190 |
| 1984 | 155 | 191 | 184 | 130 | 212 | 216 | 218 | 218 | 216 | 215 | 214 | 213 |
| 1985 | 197 | 191 | 203 | 212 | 225 | 227 | 225 | 225 | 225 | 225 | 221 | 216 |
| 1986 | 195 | 198 | 206 | 221 | 225 | 226 | 231 | 234 | 233 | 238 | 235 | 220 |

TABLE 3
Detroit River
Coordinated Monthly Mean Outflows
(1000 cfs)

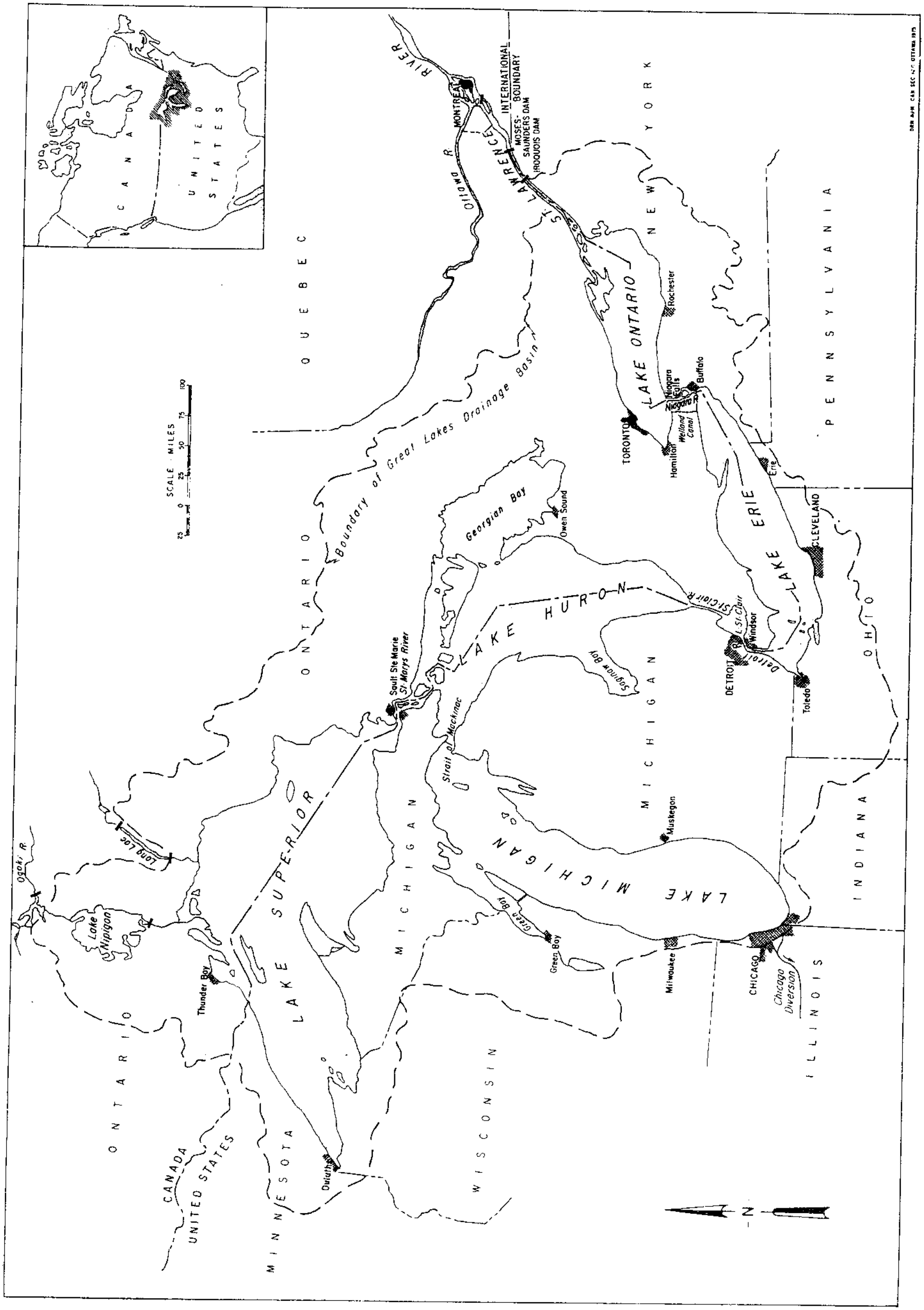
| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1900 | 152 | 147 | 148 | 186 | 187 | 190 | 194 | 196 | 196 | 197 | 199 | 190 |
| 1901 | 175 | 142 | 159 | 128 | 177 | 199 | 204 | 205 | 201 | 198 | 197 | 191 |
| 1902 | 150 | 155 | 180 | 180 | 187 | 194 | 202 | 198 | 193 | 188 | 188 | 188 |
| 1903 | 151 | 144 | 181 | 192 | 192 | 197 | 201 | 195 | 197 | 198 | 196 | 201 |
| 1904 | 160 | 165 | 162 | 200 | 201 | 204 | 206 | 208 | 206 | 205 | 203 | 196 |
| 1905 | 135 | 156 | 172 | 195 | 202 | 208 | 212 | 212 | 209 | 210 | 205 | 201 |
| 1906 | 194 | 149 | 169 | 191 | 206 | 209 | 210 | 208 | 203 | 200 | 201 | 185 |
| 1907 | 169 | 153 | 176 | 201 | 205 | 203 | 209 | 209 | 208 | 206 | 201 | 196 |
| 1908 | 153 | 146 | 177 | 200 | 205 | 209 | 212 | 212 | 202 | 202 | 195 | 190 |
| 1909 | 176 | 132 | 150 | 192 | 197 | 197 | 198 | 196 | 195 | 193 | 190 | 176 |
| 1910 | 166 | 138 | 175 | 186 | 194 | 191 | 188 | 187 | 186 | 188 | 186 | 174 |
| 1911 | 135 | 138 | 164 | 173 | 181 | 184 | 184 | 185 | 181 | 183 | 182 | 178 |
| 1912 | 140 | 139 | 162 | 176 | 186 | 192 | 194 | 194 | 196 | 198 | 200 | 197 |
| 1913 | 187 | 148 | 161 | 201 | 202 | 201 | 203 | 201 | 197 | 201 | 200 | 191 |
| 1914 | 166 | 156 | 161 | 182 | 192 | 192 | 192 | 196 | 195 | 192 | 194 | 187 |
| 1915 | 133 | 159 | 160 | 180 | 185 | 184 | 186 | 188 | 185 | 184 | 184 | 178 |
| 1916 | 178 | 153 | 139 | 183 | 196 | 194 | 199 | 204 | 200 | 199 | 199 | 197 |
| 1917 | 159 | 160 | 189 | 202 | 206 | 206 | 211 | 215 | 205 | 208 | 206 | 172 |
| 1918 | 153 | 169 | 172 | 182 | 219 | 220 | 218 | 215 | 214 | 206 | 210 | 202 |
| 1919 | 204 | 188 | 196 | 204 | 206 | 201 | 201 | 204 | 201 | 198 | 200 | 194 |
| 1920 | 123 | 140 | 169 | 193 | 192 | 200 | 203 | 202 | 202 | 201 | 193 | 182 |
| 1921 | 188 | 131 | 185 | 187 | 190 | 191 | 191 | 189 | 185 | 188 | 179 | 183 |
| 1922 | 159 | 140 | 166 | 180 | 182 | 195 | 194 | 193 | 190 | 188 | 187 | 179 |
| 1923 | 147 | 136 | 157 | 172 | 174 | 186 | 184 | 184 | 183 | 183 | 180 | 163 |
| 1924 | 160 | 122 | 153 | 159 | 170 | 179 | 179 | 181 | 181 | 178 | 173 | 156 |
| 1925 | 143 | 132 | 153 | 155 | 160 | 167 | 167 | 165 | 161 | 163 | 160 | 152 |
| 1926 | 114 | 112 | 132 | 153 | 164 | 162 | 163 | 164 | 163 | 166 | 166 | 164 |
| 1927 | 119 | 126 | 143 | 169 | 172 | 178 | 180 | 178 | 175 | 177 | 176 | 173 |
| 1928 | 160 | 138 | 134 | 176 | 188 | 188 | 191 | 195 | 197 | 201 | 201 | 201 |
| 1929 | 180 | 164 | 202 | 218 | 228 | 226 | 227 | 223 | 216 | 209 | 211 | 189 |
| 1930 | 166 | 168 | 200 | 202 | 204 | 202 | 207 | 204 | 200 | 199 | 186 | 180 |
| 1931 | 154 | 116 | 122 | 175 | 174 | 174 | 176 | 171 | 169 | 170 | 171 | 167 |
| 1932 | 161 | 164 | 134 | 158 | 166 | 166 | 167 | 166 | 162 | 159 | 157 | 160 |
| 1933 | 154 | 133 | 149 | 160 | 162 | 170 | 166 | 162 | 158 | 156 | 156 | 147 |
| 1934 | 118 | 121 | 143 | 157 | 157 | 158 | 159 | 160 | 159 | 159 | 155 | 157 |
| 1935 | 140 | 157 | 145 | 160 | 166 | 160 | 167 | 167 | 165 | 163 | 162 | 142 |
| 1936 | 140 | 133 | 150 | 162 | 168 | 173 | 172 | 169 | 172 | 172 | 168 | 161 |
| 1937 | 165 | 130 | 159 | 167 | 170 | 165 | 164 | 164 | 163 | 167 | 165 | 152 |
| 1938 | 131 | 153 | 143 | 172 | 175 | 178 | 182 | 184 | 182 | 183 | 182 | 174 |
| 1939 | 162 | 148 | 148 | 180 | 181 | 184 | 187 | 188 | 190 | 188 | 186 | 179 |

TABLE 3
(Continued)
Detroit River
Coordinated Monthly Mean Outflows
(1000 cfs)

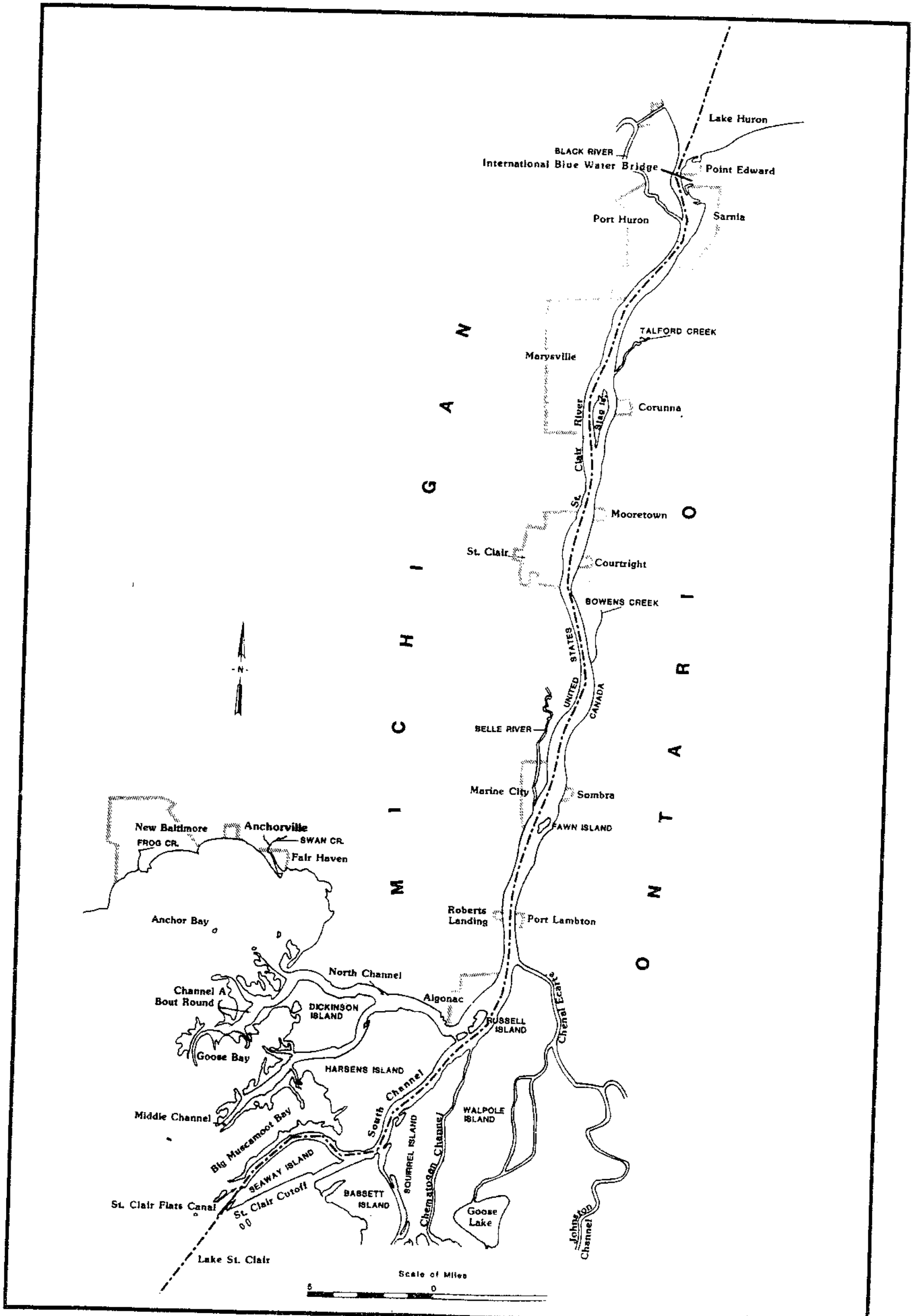
| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1940 | 137 | 143 | 149 | 170 | 170 | 179 | 177 | 176 | 180 | 179 | 181 | 176 |
| 1941 | 152 | 130 | 148 | 165 | 177 | 177 | 177 | 173 | 175 | 178 | 181 | 178 |
| 1942 | 153 | 114 | 155 | 184 | 186 | 192 | 192 | 190 | 191 | 184 | 187 | 179 |
| 1943 | 158 | 148 | 178 | 188 | 202 | 202 | 210 | 211 | 210 | 208 | 206 | 198 |
| 1944 | 152 | 165 | 169 | 196 | 198 | 202 | 203 | 199 | 198 | 199 | 195 | 195 |
| 1945 | 158 | 157 | 182 | 188 | 199 | 202 | 206 | 202 | 200 | 204 | 196 | 192 |
| 1946 | 180 | 168 | 195 | 202 | 201 | 204 | 202 | 199 | 194 | 190 | 188 | 186 |
| 1947 | 162 | 152 | 178 | 200 | 196 | 201 | 206 | 206 | 204 | 200 | 201 | 194 |
| 1948 | 184 | 175 | 192 | 197 | 208 | 200 | 202 | 200 | 194 | 185 | 181 | 178 |
| 1949 | 184 | 180 | 155 | 182 | 180 | 179 | 182 | 182 | 178 | 174 | 170 | 169 |
| 1950 | 170 | 152 | 153 | 180 | 176 | 180 | 186 | 187 | 190 | 190 | 187 | 186 |
| 1951 | 162 | 167 | 191 | 198 | 204 | 208 | 214 | 216 | 214 | 216 | 218 | 222 |
| 1952 | 224 | 210 | 218 | 226 | 224 | 228 | 230 | 232 | 232 | 224 | 218 | 215 |
| 1953 | 210 | 206 | 212 | 212 | 218 | 222 | 226 | 224 | 220 | 214 | 212 | 206 |
| 1954 | 173 | 165 | 208 | 206 | 210 | 214 | 218 | 215 | 214 | 220 | 217 | 212 |
| 1955 | 208 | 190 | 210 | 208 | 210 | 210 | 212 | 204 | 202 | 198 | 192 | 188 |
| 1956 | 158 | 140 | 173 | 189 | 207 | 196 | 196 | 200 | 198 | 192 | 188 | 182 |
| 1957 | 153 | 154 | 176 | 179 | 181 | 181 | 190 | 185 | 187 | 180 | 180 | 178 |
| 1958 | 142 | 132 | 170 | 157 | 178 | 175 | 176 | 174 | 173 | 170 | 165 | 162 |
| 1959 | 122 | 132 | 163 | 166 | 171 | 172 | 174 | 175 | 175 | 178 | 180 | 182 |
| 1960 | 178 | 152 | 167 | 192 | 194 | 202 | 204 | 206 | 205 | 204 | 200 | 188 |
| 1961 | 177 | 183 | 190 | 190 | 189 | 188 | 190 | 191 | 190 | 191 | 190 | 184 |
| 1962 | 160 | 146 | 183 | 185 | 188 | 190 | 189 | 187 | 187 | 182 | 178 | 165 |
| 1963 | 148 | 132 | 159 | 170 | 171 | 174 | 174 | 174 | 171 | 169 | 166 | 160 |
| 1964 | 140 | 130 | 150 | 153 | 159 | 159 | 161 | 163 | 163 | 162 | 161 | 156 |
| 1965 | 140 | 144 | 153 | 168 | 168 | 171 | 174 | 175 | 177 | 182 | 181 | 181 |
| 1966 | 176 | 168 | 177 | 183 | 185 | 185 | 186 | 184 | 183 | 178 | 177 | 181 |
| 1967 | 172 | 162 | 177 | 190 | 185 | 191 | 197 | 195 | 192 | 191 | 194 | 192 |
| 1968 | 168 | 182 | 186 | 185 | 186 | 192 | 196 | 199 | 198 | 200 | 198 | 197 |
| 1969 | 171 | 194 | 192 | 200 | 202 | 206 | 210 | 213 | 210 | 208 | 210 | 202 |
| 1970 | 149 | 170 | 196 | 201 | 201 | 205 | 208 | 207 | 207 | 206 | 207 | 205 |
| 1971 | 190 | 180 | 208 | 210 | 209 | 214 | 216 | 217 | 216 | 213 | 210 | 207 |
| 1972 | 202 | 192 | 203 | 204 | 209 | 214 | 216 | 220 | 222 | 222 | 223 | 218 |
| 1973 | 217 | 200 | 223 | 221 | 224 | 228 | 230 | 231 | 229 | 227 | 226 | 221 |
| 1974 | 215 | 214 | 220 | 220 | 226 | 228 | 233 | 230 | 227 | 222 | 219 | 214 |
| 1975 | 209 | 207 | 205 | 217 | 217 | 222 | 223 | 223 | 224 | 216 | 211 | 209 |
| 1976 | 173 | 190 | 215 | 218 | 226 | 223 | 228 | 224 | 216 | 211 | 205 | 185 |
| 1977 | 170 | 180 | 203 | 197 | 192 | 193 | 194 | 192 | 194 | 198 | 198 | 201 |
| 1978 | 180 | 180 | 190 | 198 | 191 | 196 | 200 | 202 | 204 | 205 | 202 | 200 |
| 1979 | 163 | 167 | 204 | 214 | 213 | 214 | 218 | 219 | 217 | 212 | 214 | 212 |

TABLE 3
(Continued)
Detroit River
Coordinated Monthly Mean Outflows
(1000 cfs)

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1980 | 209 | 200 | 205 | 210 | 209 | 212 | 214 | 214 | 214 | 212 | 208 | 206 |
| 1981 | 164 | 200 | 204 | 204 | 209 | 206 | 210 | 209 | 214 | 213 | 207 | 202 |
| 1982 | 167 | 166 | 200 | 198 | 197 | 201 | 202 | 205 | 205 | 203 | 205 | 207 |
| 1983 | 201 | 201 | 205 | 208 | 215 | 218 | 220 | 219 | 217 | 215 | 212 | 200 |
| 1984 | 165 | 208 | 205 | 143 | 210 | 223 | 221 | 222 | 221 | 220 | 220 | 220 |
| 1985 | 206 | 204 | 228 | 226 | 228 | 229 | 228 | 229 | 230 | 230 | 238 | 224 |
| 1986 | 205 | 205 | 226 | 227 | 227 | 232 | 234 | 236 | 238 | 250 | 239 | 231 |

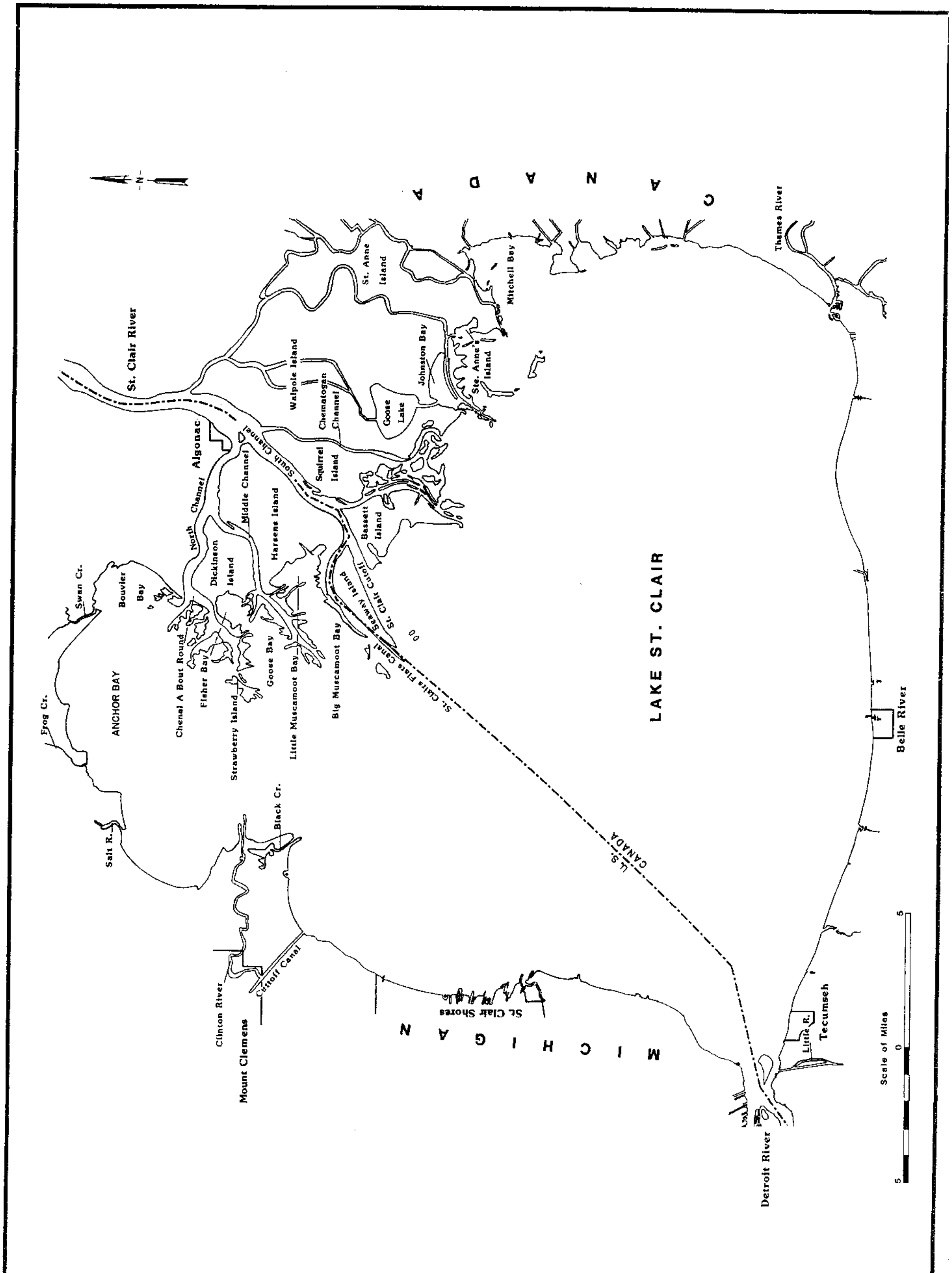



**Great Lakes Basin** **Figure 1**



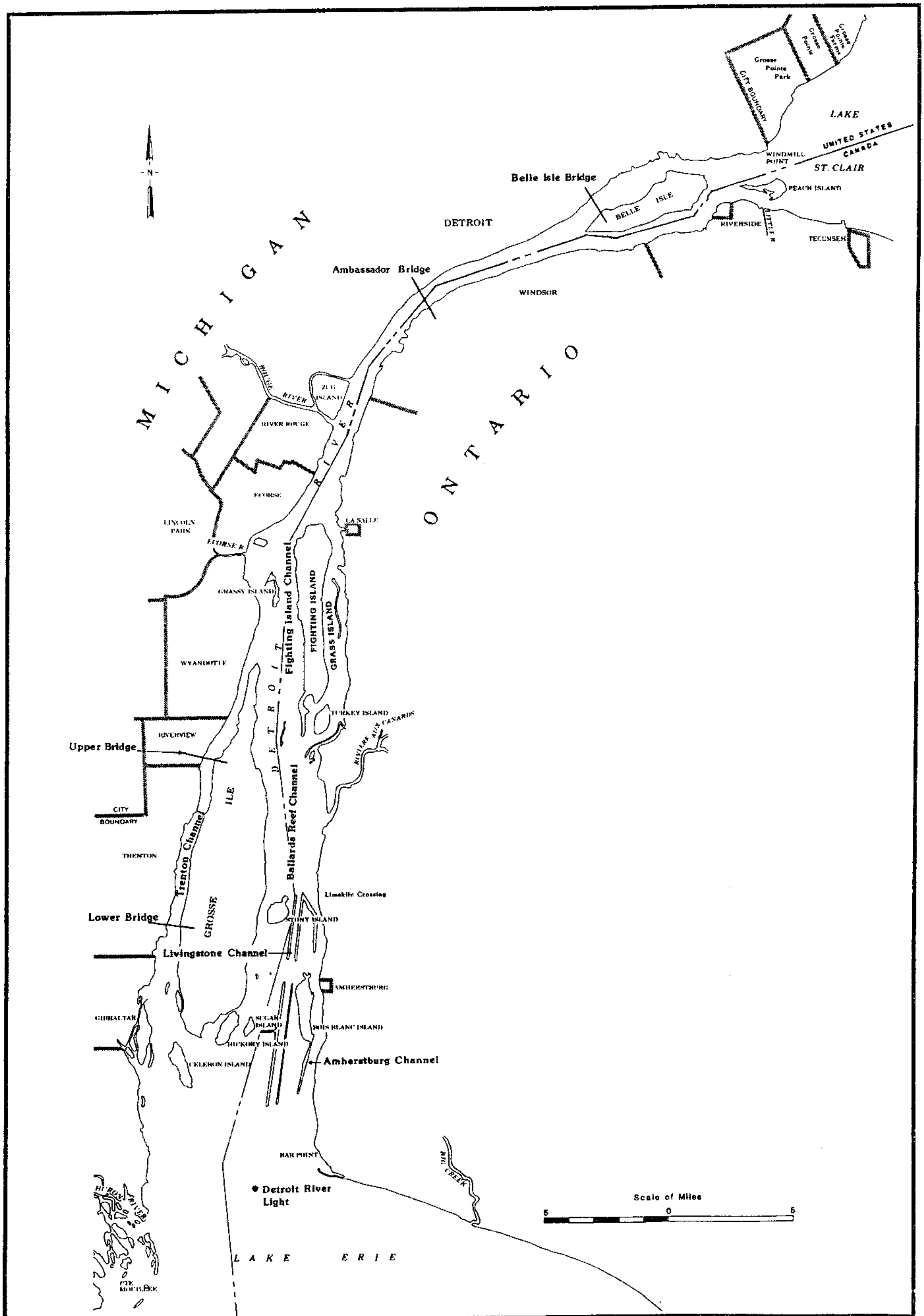

St. Clair River

**Figure 2**



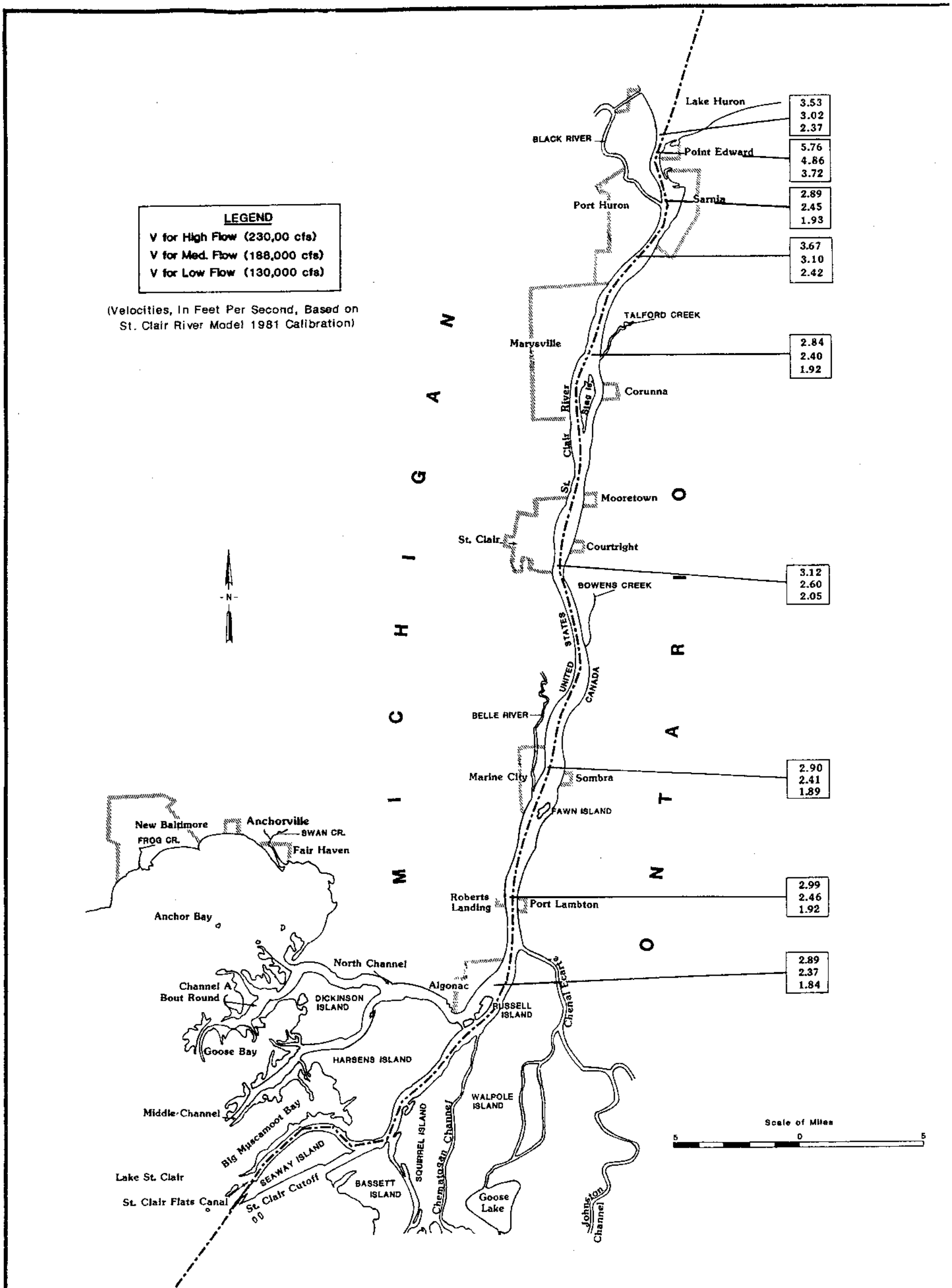

Lake St. Clair

Figure 3



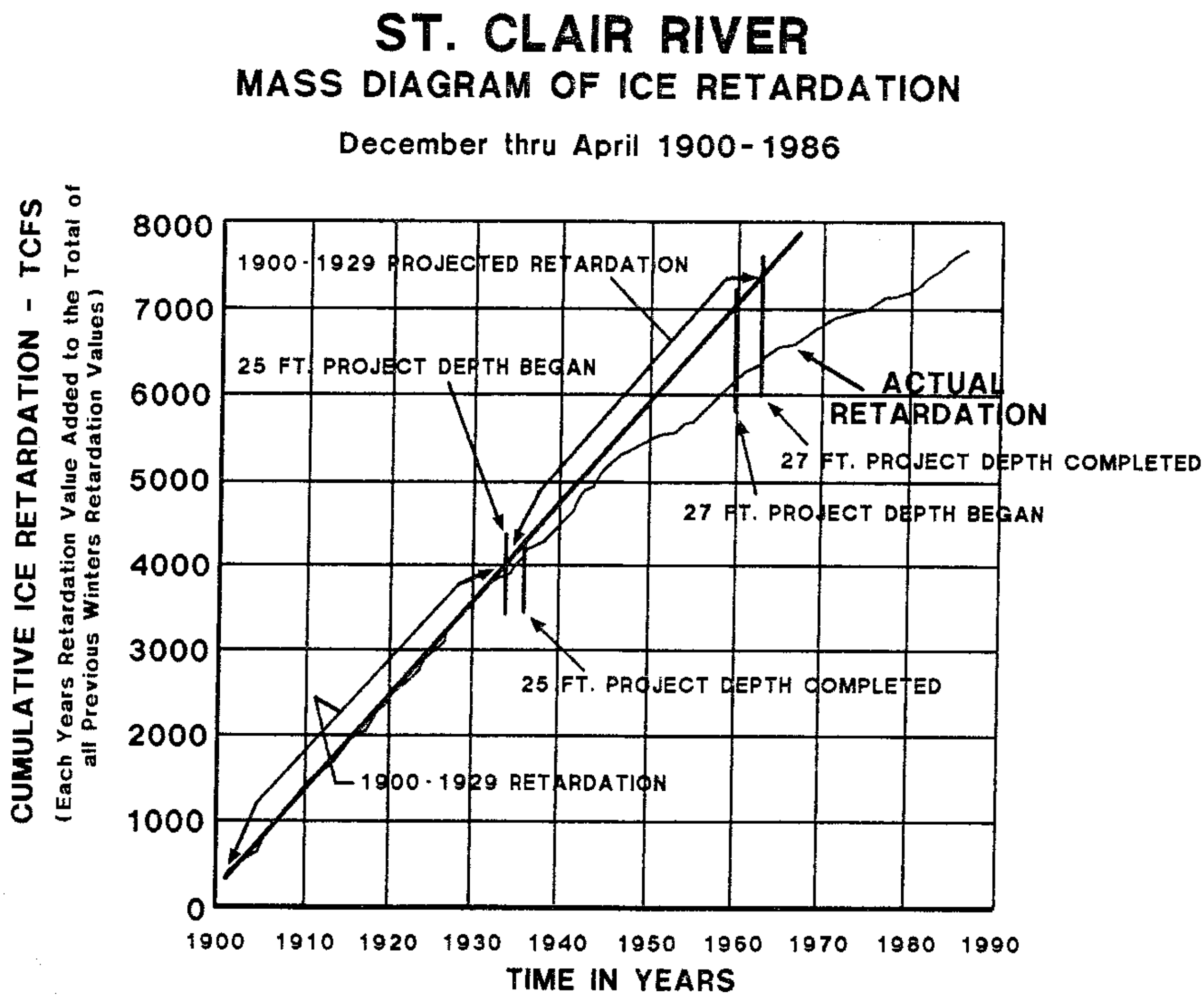

Detroit River

Figure 4



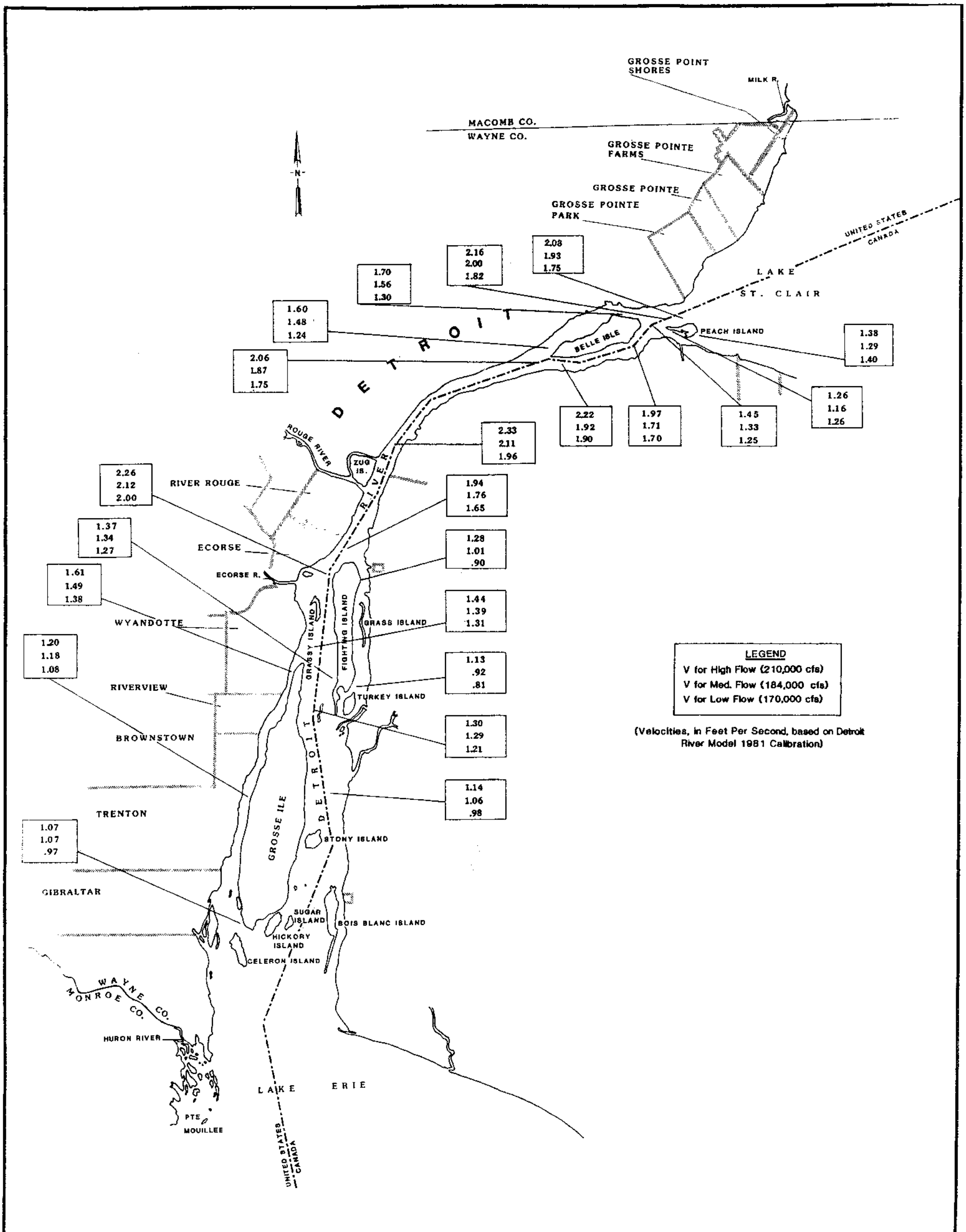

St. Clair River Average Velocities

Figure 5

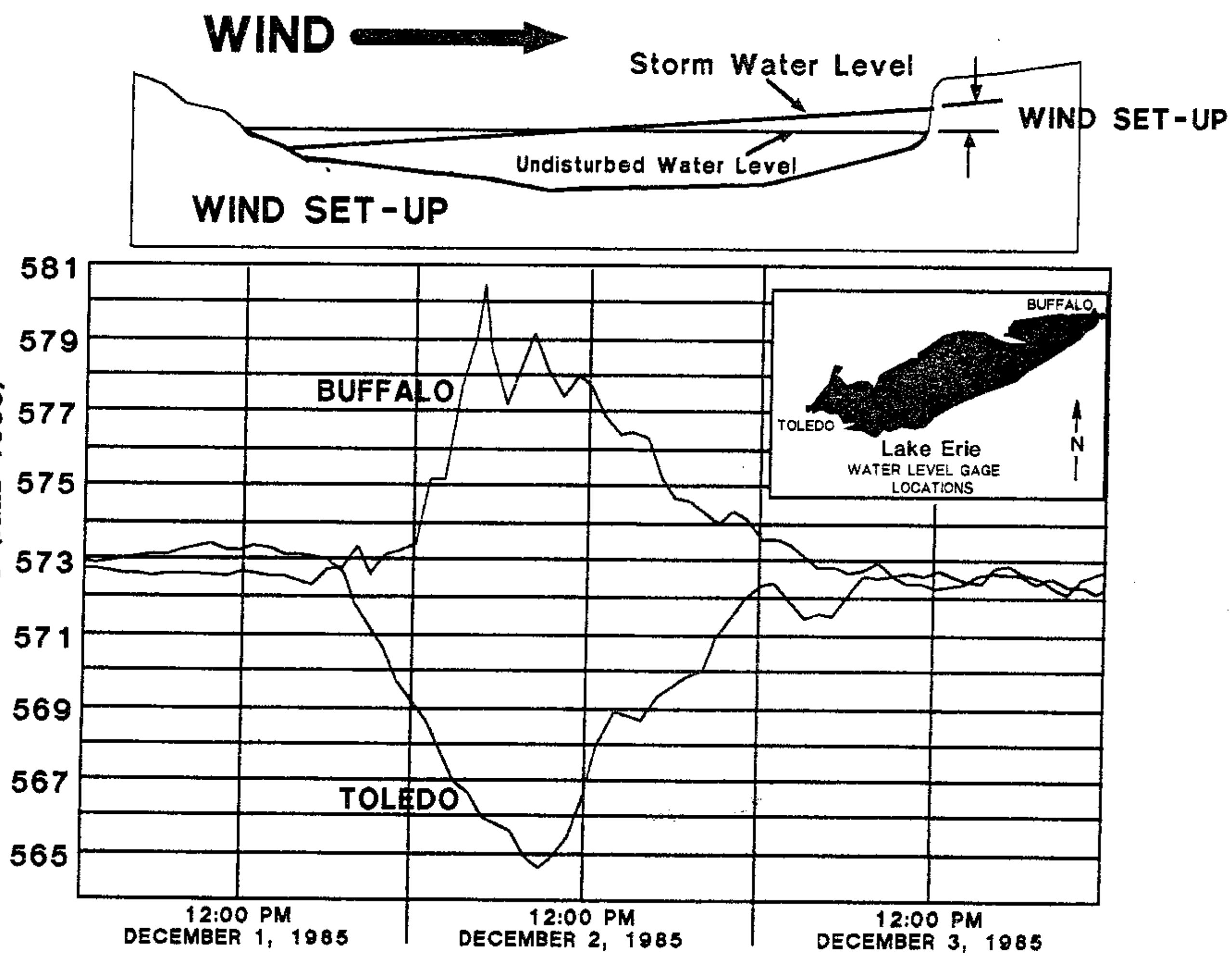



St. Clair River Mass Diagram of Ice Retardation

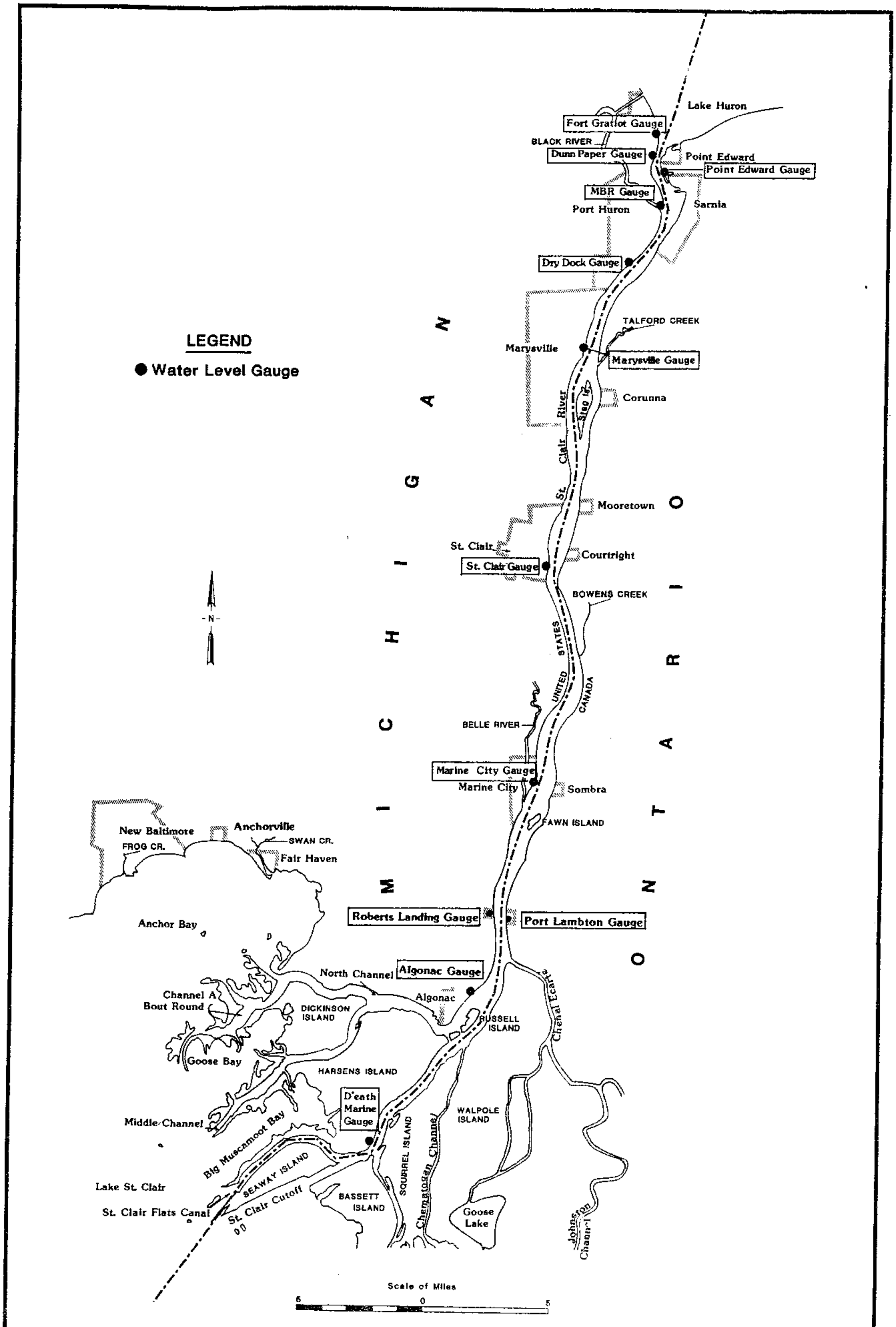
Figure 6




**Detroit River Average Velocities** **Figure 7**

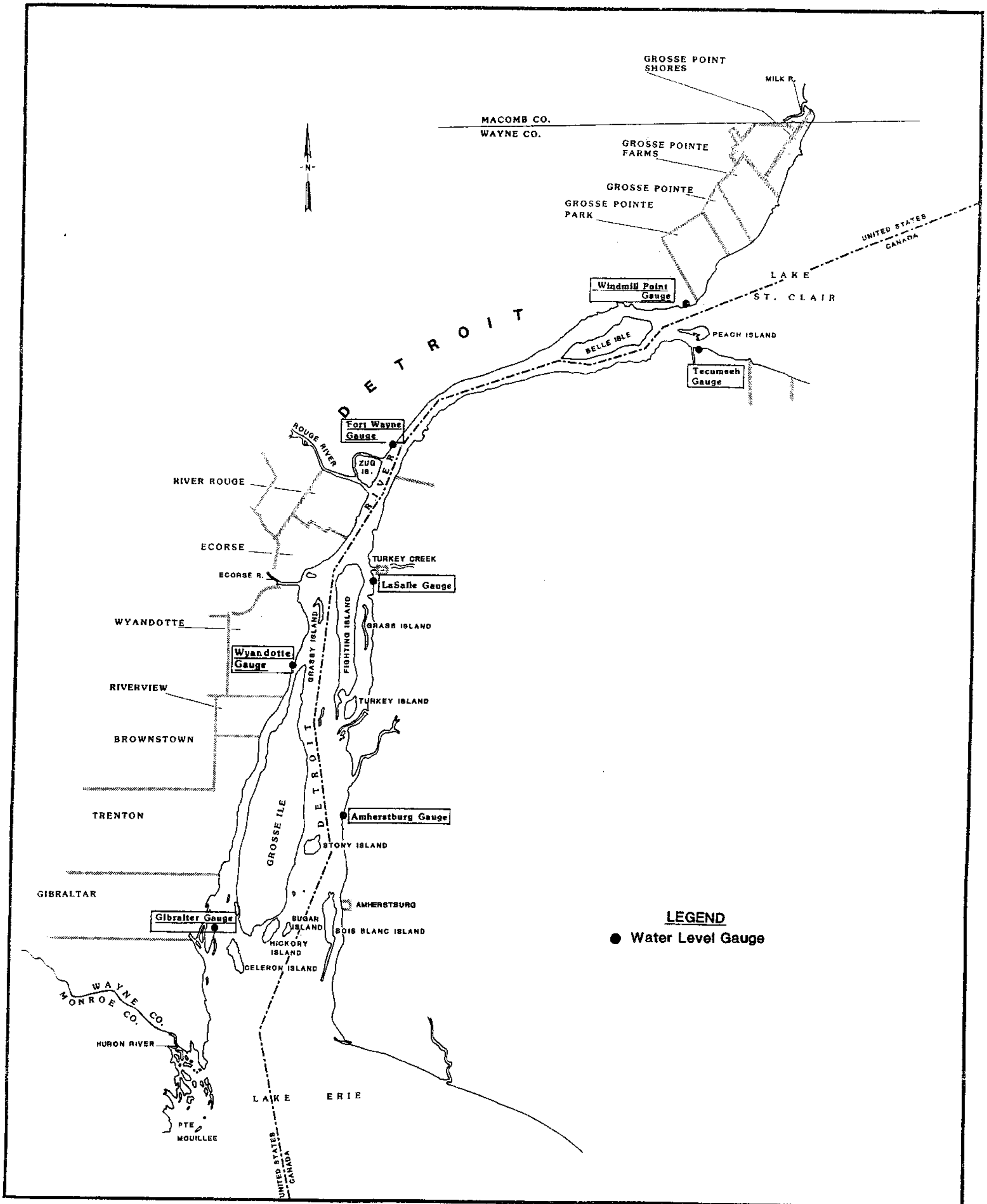



Surge and Seiche Effect on Lake Erie During Storm of December 2, 1985 Figure 8



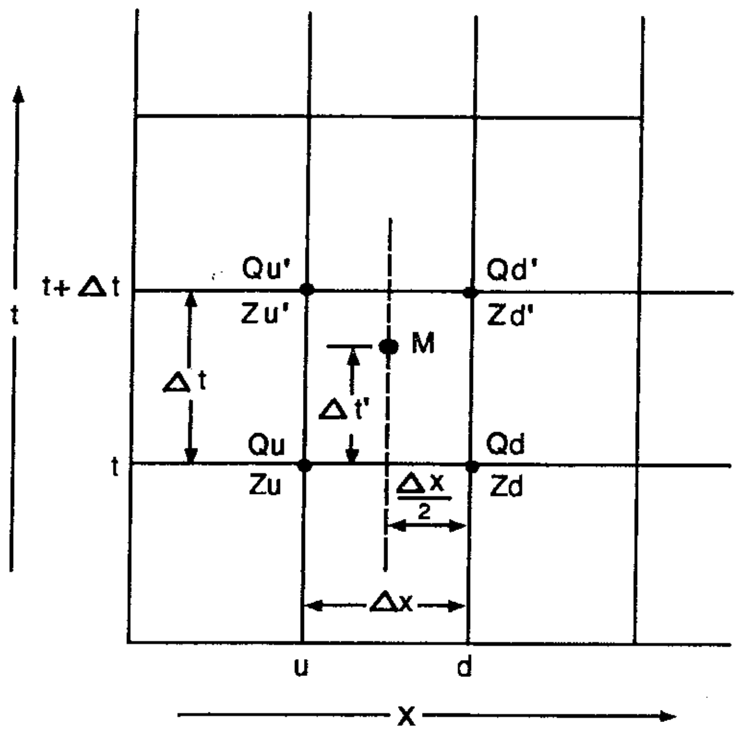

St. Clair River Water Level Gauge Sites

Figure 9




Detroit River Water Level Gauge Sites

Figure 10




**Implicit Computation Network** **Figure 11**

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